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Measurement of Light Hydrocarbons and Oxidant Transport

Houston Area 1976

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MEASUREMENT OF LIGHT HYDROCARBONS AND OXIDANT TRANSPORT
Houston Study 1976

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CONTENTS

ABSTRACT iii

FIGURES vi

TABLES viii

ACKNOWLEDGEMENTS x

1. Introduction 1

2. Conclusions 3

3. Experimental Procedure 5
   Site description 5
   Field laboratory 5
   Ground instrumentation 7
   Meteorological measurements 10
   Aircraft description 10
   Aircraft measurements 11
   Data handling procedures 15
   Calibration procedures 16

4. Results and Discussion 19
   Meteorology 19
   Hydrocarbons 20
   Oxidants 41
   Secondary pollutant production and transport 60
   Oxides of nitrogen 86
   Halocarbons 89
   Visibility and particles 90

REFERENCES 98

APPENDICES

A. Pollutant and meteorological data 100
B. Aircraft data 126
C. Individual hydrocarbon data 233

FIGURES

Number		Page
1	Map of Houston area.	6
2	Diagrams of Cessna aircraft employed in Houston field study. . .	12
3	Total Ion Chromatogram for sample collected in Houston	23
4	FID chromatogram for sample collected between 6 and 9 am on July 12 at WSU trailer site (a: C_2-C_5 analysis; b: C_5-C_{10} analysis).	26,27
5	Summary of 6-9 am hydrocarbon data obtained at the three Houston area ground sampling sites	34
6	Peak hourly average ozone readings at two Houston area ground sites.	48
7	Diurnal Ozone pattern recorded between July 7 and 12, 1976 . . .	50
8	Afternoon flight path on July 5 with ozone concentrations (ppb) marked along the route (see Appendix B for time, altitude and other details).	51
9	Afternoon flight path on July 10 with ozone concentrations (ppb) marked along the route (see Appendix B for time, altitude and other details).	52
10	Morning (a) and afternoon (b) flight paths on July 8 with ozone concentrations (ppb) marked along the route (see Appendix B for time, altitude and other details).	54
11	Morning (a) and afternoon (b) vertical soundings conducted on July 8, 1976 (see Appendix B for details)	55
12	Relationship between peak hourly ozone and PAN concentrations in Houston during July, 1976.	59
13	Diurnal ozone and PAN patterns in Houston during the period of July 7-12, 1976	61
14	Surface weather map for the morning of July 12, 1976 (7 am EST)	62
15	Morning flight path on July 12 with ozone concentrations (ppb) marked along the route (see text and Appendix B for time, altitude and other details).	64

Number Page

16 Ozone and temperature vertical profiles at about 9 am on July 12, 1976. 66

17 Nitric oxide and nitrogen dioxide vertical profiles at about 9 am on July 12, 1976 67

18 Ozone and temperature vertical profiles at about 11 am on July 12, 1976. 68

19 Ozone and temperature vertical profiles at about 3:15 pm on July 12, 1976. 69

20 Ozone and temperature vertical profiles at about 5:15 pm on July 12, 1976. 70

21 Pollutant changes at the WSU trailer site on July 12, 1976. . . 74

22 Afternoon flight path on July 12 with ozone concentrations (ppb) marked along the route (see text and Appendix B for time, altitude and other details) 75

23 High ozone region (shaded area) to the west of Houston on the afternoon of July 8, 1976 (see Appendix B for flight details) 78

24 Pollutant changes at the WSU trailer site on July 8, 1976 . . . 80

25 Ground level 6-9 am hydrocarbon and NO_x concentrations recorded at the WSU trailer site. 87

26 Relationship between ozone concentration and b_{scat} values in plume approximately 90 miles downwind of Houston plume (Flt #10; July 12, 1976). 93

27 Relationship between ozone concentration and b_{scat} values in plume approximately 45 miles downwind of Houston (Flt #10; July 12, 1976). 94

28 Relationship observed between ozone concentration and b_{scat} values during vertical sounding in Houston plume (Flt #10; July 12, 1976). 95

29 Relationship between ozone concentration and b_{scat} values directly over Houston (Flt #7; July 8, 1976). 96

30 Sulfate data obtained during the afternoon of July 22, 1976 (Flt #26 - see Appendix B for details). 97

TABLES

Number | | Page
1 Meteorlogical Summary for the July 1-25 Period 21
2 Hydrocarbon Levels in 6-9 am WSU Trailer Sample on July 12, 1976. 25
3 Individual Hydrocarbon Concentrations ($\mu g/m^3$) in Samples Collected Between 6 and 9 am at the WSU Trailer Site 28
4 Individual Hydrocarbon Concentrations ($\mu g/m^3$) in Samples Collected between 6 and 9 am at the South Site 30
5 Individual Hydrocarbon Concentrations ($\mu g/m^3$) in Samples Collected Between 6 and 9 am at the North Site 32
6 Hydrocarbon Compositional Comparison at Two Sites Between 6 and 9 am on July 16, 17, 19 and 20, 1976 36
7 Individual Hydrocarbon Concentrations ($\mu g/m^3$) in Samples Collected During the Afternoon Hours at the WSU Trailer Site 37
8 Average Vehicular Component Based on C_2-C_5 Hydrocarbons at at Two Houston Locations 38
9 Average Vehicular Contribution at Three Houston Area Sampling Sites 39
10 Comparison of Houston Area Hydrocarbon Concentrations. 40
11 Individual Hydrocarbon Concentrations ($\mu g/m^3$) in Samples Considered to be Representative of Background Air. 42
12 Individual Hydrocarbon Concentrations ($\mu g/m^3$) in Samples Collected in Air Masses Containing Ozone Levels Greater than 80 ppb. 43
13 Annual Statistics for Ozone in the Houston Area, 1974-1976 . . 45
14 Ozone Hourly Average Concentrations (ppb) at WSU Trailer Site During the Period July 1-25, 1976 46
15 PAN Hourly Average Concentrations (ppb) at WSU Trailer Site During the Period July 2-23, 1976 57
16 Winds Measured At the WSU Trailer Site on July 12, 1976. . . . 63

Number		Page
17	Surface Ozone Concentrations (ppb) on July 12.	71
18	Surface Measurements at WSU Trailer Site on July 12, 1976. .	72
19	Surface Winds Recorded at Houston Area Airports on July 8, 1976	77
20	Hydrocarbon, Halocarbon and CO Levels in Sample A-1 Collected E of Baytown (3000') at 9:15 am on July 8, 1976	81
21	Hydrocarbon, Halocarbon and CO Levels in Sample A-2 Collected W of Houston (1000') at 10:10 am on July 8, 1976	82
22	Hydrocarbon, Halocarbon and CO Levels in Sample A-3 Collected N of Houston (1250') at 4:00 pm on July 8, 1976	83
23	Hydrocarbon Levels in 6-9 am WSU Trailer Site Sample on July 8, 1976.	84
24	Hydrocarbon - Acetylene Ratios in Morning and Afternoon Air Masses on July 8, 1976	85
25	Hydrocarbon/NO$_x$ Ratios in "High Oxidant" Areas Around Houston.	88
26	Hydrocarbon/NO$_x$ Ratios in Various Types of Air Masses. . . .	89
27	Halocarbon Concentrations in the Houston Area.	91

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SECTION 1

INTRODUCTION

Air Pollution problems in the Houston area have received considerable attention in recent years. Houston is one of the many large U.S. cities where summertime oxidant levels commonly exceed the National Ambient Air Quality Standard (NAAQS). Although the sequence of chemical transformations which gives rise to photochemical oxidants is very complex and not completely understood, the general mechanism for the formation of ozone and associated secondary products has been established. Basically, oxides of nitrogen (NO_x) and reactive hydrocarbons participate in a series of reactions which are initiated and sustained by natural sunlight. While several chemical species are produced by this process, ozone is the product most commonly measured and has been used almost exclusively as an indicator of the degree of photochemical oxidant pollution.

A hydrocarbon control strategy has been adopted by the United States Environmental Protection Agency as the optimum means for reducing oxidants. Appendix J to Title 40, Part 51 of the Code of Federal Regulations (1) has been used to estimate the degree of reduction in hydrocarbon emissions needed to achieve the primary NAAQS for photochemical oxidants. Appendix J was derived from envelope curves enclosing points depicting 6-9 am ambient non-methane hydrocarbon concentrations and corresponding daily maximum ambient oxidant concentrations measured in several cities in the United States.

The applicability of this type of control strategy in the Houston area has been questioned since air quality studies seem to indicate that little correlation exists between ground level 6-9 am hydrocarbon levels and oxidant concentrations recorded later in the day. It is estimated that hydrocarbon emissions were reduced by about 40% during the 1974 to 1975 period in Houston (2). However, a similar reduction in oxidant levels has not been recorded.

A better understanding of local pollutant dispersion and transport processes is especially needed in the Houston area. Compared to other large metropolitan regions, the Houston vicinity is unique because of its unusually large industrial complex. Point sources contribute approximately 60% of the hydrocarbon and NO_x emissions, while in other cities the industrial contribution is usually much less than 50%. Three dimensional information concerning pollutant behavior is very important because of the complex nature of emission patterns from the various sources (e.g. surface emissions, low stacks, tall stacks, etc.). Stack effluents many times have sufficient plume rise to become imbedded in stable inversion layers. Processes that control ozone formation and persistence in these elevated layers often differ from those near the surface.

Washington State University conducted an air quality study in Houston during July, 1976. Through the use of both an instrumented aircraft and a ground laboratory we were able to obtain considerable information concerning the formation and transport of oxidants. Results from this field program are described in this report.

SECTION 2

CONCLUSIONS

Hydrocarbon concentrations (6-9 am) at three ground level sites in the Houston area generally fell in the range of 200-1000 $\mu g/m^3$. However, there were occasions when the hydrocarbon total exceeded 2000 $\mu g/m^3$. The extreme hydrocarbon concentrations ($>2000\ \mu g/m^3$) were most often observed at the site in north Houston. On mornings when hydrocarbon concentrations in the 2000-3000 $\mu g/m^3$ range were recorded, it was common to find as much as 90% of the hydrocarbon burden comprised of aromatic species. Afternoon hydrocarbon levels at the WSU trailer site in northwest Houston averaged about a factor of three lower than those measured during the 6-9 am period.

Background hydrocarbon concentrations averaged about 40 $\mu g/m^3$. Samples collected in air masses containing elevated ozone exhibited hydrocarbon concentrations in the 200 $\mu g/m^3$ range and thus were considerably above the background level. The hydrocarbon content that could be ascribed to automotive tailpipe emissions between 6 and 9 am at the three sampling sites varied from 25 to 31%. A similar vehicular content ($\sim$25%) was determined from hydrocarbon samples collected by aircraft in the downwind Houston plume.

Ozone concentrations at the WSU trailer site equalled or exceeded the 80 ppb NAAQS on seven of the 25-day sampling period. It was not uncommon for aircraft measured ozone concentrations to exceed 80 ppb on days when ground level concentrations were much below the standard. There is little doubt that ozone concentrations in the region downwind of Houston generally exceed those monitored at ground level stations in the Houston urban-industrial complex. Between July 1 and 24, 1976 there were no "blanket" ozone episodes in southern Texas. Consequently, we believe that oxidants measured in the Houston area during the July study period resulted from precursors emitted in the immediate Houston area. There was no evidence of surface ozone enhancement due to subsiding air masses from aloft.

The presence of PAN in the Houston atmosphere was primarily limited to the daylight hours. Elevated PAN concentrations were observed to persist into the nighttime hours only on two occasions. The highest hourly average PAN concentration was 11.5 ppb; however, the average of all measurements between 10 am and 4 pm was only 1.0 ppb. On a daily basis there existed a good correlation between PAN and ozone. On days when ozone showed high peak values, PAN concentrations peaked as well.

The Houston plume was detectable for long distances downwind. Aircraft data collected on July 12, clearly show a pronounced ozone plume as far as 90 miles downwind of Houston. Ozone levels approaching 190 ppb were recorded at that distance and they remained elevated over a cross-sectional distance of about 45 miles. A reduction in visual range always coincided with elevated ozone in the downwind plume.

Hydrocarbon - NO_x ratios during the 6-9 am period generally fell in a range of 7.5 to 18.5 at the northwest Houston ground sampling site. Similar Hc/NO_x ratios were observed in air masses that contained high oxidant levels. On several occasions the ground level, diurnal, pollutant patterns in Houston were consistent with a photochemical oxidant producing mechanism.

Ambient fluorocarbon-11 concentrations averaged between 400 and 650 ppt in northwest Houston. This is high when compared to average background concentration in upwind areas of about 140 ppt. This difference was used as an aid for tracing the Houston plume. Ground level carbon tetrachloride concentrations averaged about 300 ppt in Houston and showed little diurnal variation.

Samples collected in the Houston vicinity for sulfate analysis exhibited concentrations ranging from near zero to 10.8 $\mu g/m^3$. In general, highest sulfate levels were recorded in areas downwind of the ship channel industrial area.

SECTION 3

EXPERIMENTAL PROCEDURE

SITE DESCRIPTION

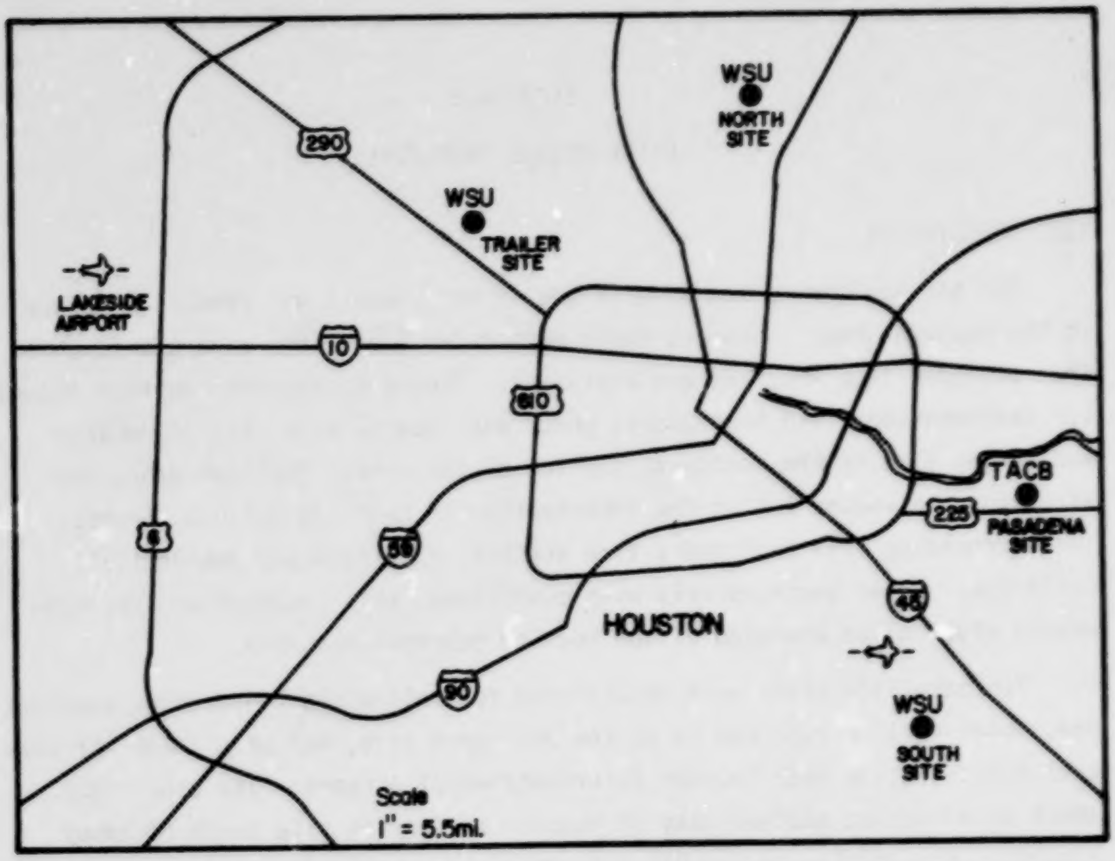
The air monitoring study described in this report was conducted mainly in the Houston area. However, there were a few long-range aircraft flights that extended into Arkansas and Louisiana. Ground operations centered around our instrumented field laboratory, which was located at a City of Houston monitoring site in the northwest section of the city. The laboratory was situated in a vacant lot at the intersection of Lane and Malibou Streets. The surrounding area included a fire station, city park and residential buildings. Under southeasterly wind conditions, this location was approximately eight miles downwind of the Houston metropolitan area.

Two satellite sites were established for collecting hydrocarbon samples. One, which will be referred to as the WSU north site, was at a Texas Air Control Board station near Houston Intercontinental Airport. The other (WSU south site) was at another City of Houston monitoring site south of Hobby Airport. In addition to the WSU collection locations, Texas Air Control Board personnel recorded individual hydrocarbon levels in Pasadena. The network provided by these sites allowed excellent coverage of air masses moving across the Houston area on the prevailing southeasterly winds (Figure 1).

The aircraft employed in this study was based at Lakeside Airport, which is about 15 miles west of Houston on Highway 10.

FIELD LABORATORY

A 23-ft. custom-built travel trailer served as our field headquarters. This laboratory contains 52 ft. of bench and rack space for accommodation of the monitoring instruments, meteorological sensors and data acquisition and


WSU
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290
WSU
TRAILER SITE
LAKESIDE AIRPORT
10
610
TACB
225
PASADENA SITE
6
59
45
HOUSTON
90
WSU
SOUTH SITE
Scale
1" = 5.5mi.

Figure 1. Map of Houston area.

reduction system. Most of this equipment is permanently mounted in the trailer for easy transport from site to site. The laboratory can be set up with most instruments fully operational in one day. Constant temperature within the trailer is maintained by two large air conditioners mounted on the roof.

Outside air is brought into the trailer through a 4-in. stainless steel line. The top of the air inlet stack is about 20 ft. above ground level. This sample line runs the full interior length of the trailer and serves as a manifold for supplying outside air to the continuously monitoring instruments. An air flow rate through the line of approximately 100 cfm is maintained by a squirrel-cage fan at the exhaust end.

Equipment is laid out within the trailer such that those instruments monitoring the reactive gases (ozone and nitric oxide) are closest to the inlet end of the manifold.

GROUND INSTRUMENTATION

A brief description of the instruments included in the field laboratory is provided below.

Ozone Monitor - A Meloy Model OA350 Ozone Analyzer was used for ozone measurements. Operation of this instrument is based on the gas-phase chemiluminescent reaction between ozone and ethylene, which produces light energy in the 300 to 600 nm region. The light emitted is detected by a photomultiplier tube and converted to an electrical signal compatible with recording devices.

NO, NO_2 and NO_x Monitor - We employed a TECO Model 14D for oxides of nitrogen measurements. This instrument employs the chemiluminescent reaction between nitric oxide and ozone as the detection technique. The 14D has dual chambers; one for NO and another for NO_x. It is capable of selective detection of NO, NO_2 and NO_x. It has a lower sensitivity limit of approximately 5 ppb for NO, NO_2 and NO_x.

Methane, Carbon Monoxide and Total Hydrocarbon Monitor - A Beckman Model 6800 Air Quality Gas Chromatograph was used for these measurements. This automated gas chromatograph employs a flame ionization detector for hydrocarbon analysis. Carbon Monoxide is reduced to methane prior to entering the detector. This instrument provides a CH_4, CO and THC reading at 5-minute intervals and is interfaced with our computer system for data reduction.

Halocarbon Monitor - A Hewlett Packard Model 5700A Gas Chromatograph equipped with a constant-current ^{63}Ni electron capture detector was used to monitor ambient levels of fluorocarbon-11, chloroform, fluorocarbon-113, methyl chloroform, carbon tetrachloride and trichloroethene. Separation was achieved on a 10-ft. x 1/8-in. stainless-steel column containing 10% SF-96 on Chromosorb W. The column was maintained at 55°C. With a carrier gas (95% argon - 5% methane) flow of 20 ml/min., three analyses could be run each hour. This instrument was automated by attaching a 1-ml sample loop, a Carle microvalve (#5518), a Carle valve actuator (#4201) and a Carle valve minder (#4101). A manual technique was used for injecting aircraft collected samples.

PAN Monitor - Peroxyacetyl nitrate levels were monitored three times per hour using an Analog Technology Corporation tritiated-scandium electron capture detector. PAN was separated from other ambient gases on a 5' x 1/8" 10% Carbowax 600 Gas Chrom Z glass column. Both the column and electron capture detector were maintained at room temperature.

Individual Light Hydrocarbon Measurements - These measurements were made with Perkin Elmer Model 900 Gas Chromatographs. The standard dual-flame instrument was used with the addition of a sub-ambient accessory. The normal carrier gas flow system was modified to include a freeze-out trap for concentrating organics in ambient air. The column used to separate light hydrocarbons was a packed capillary (20' x 1/16") containing Durapak n-Octane/Porasil C. When operated with a carrier gas (He) flow of ~50 ml/ min. and temperature-programmed from -70 to 80° at 24°/min., this column provided excellent resolution of the C_2-C_5 hydrocarbon fraction. This hydrocarbon analysis method was not automated. Analysis for hydrocarbons in the C_5-C_{10} molecular weight range was performed on a

30 meter SE-30 glass capillary column. The same type of cryogenic concentration procedure described for the light hydrocarbons was used. The resolving power of the glass capillary column was enhanced by employing a sub-ambient temperature programming method.

Mass Spectrometric Analysis - A Hewlett Packard 5930A Mass Spectrometer coupled with a Hewlett Packard 5700 Gas Chromatograph was employed for gc-ms analysis. The mass spectrometer is a standard quadrupole instrument which has been modified by the addition of a second 4-in. diffusion pump. The glass capillary columns we use for hydrocarbon analyses require a low carrier gas flow rate (< 5 ml/min.). This, coupled with the extra pumping capacity, permits the total gc column effluent to be passed directly into the mass spectrometer. Thus, the mass spectrometer serves exactly the same function as the flame ionization detector and a chromatogram resulting from the flame detector will be nearly identical to that recorded by monitoring the total ion current in the mass spectrometer. This makes it relatively easy to verify peak assignments. Samples collected and analyzed in the field using the flame ionization detector were shipped to our mass spec laboratory where they were analyzed using the same chromatographic conditions as in the field. Hydrocarbon identities reported in this study are based on retention time comparisons with standards plus mass spectral fragmentation patterns.

All the ground instruments, with the exception of the Perkin-Elmer 900 gas chromatograph, obtained air samples on a continuous basis from the trailer manifold. Samples for hydrocarbon analysis were taken from the trailer manifold, Teflon bags or metal canisters. These canisters were constructed of stainless steel with all the inner surfaces polished using the "Summa" process. The cans were filled with air using a metal bellows pump and sealed by closing two bellows valves. By pressurizing these containers to 10 psig, about 5 liters of air could be obtained for sampling purposes. These stainless-steel containers provided the means by which ambient air samples could be returned to our home laboratory in Pullman, WA, for mass spectrometric analysis.

METEOROLOGICAL MEASUREMENTS

Instrumentation used to measure the various meteorological parameters included three separate systems:

1) Climet CI-60 Data System - This instrument package contained sensors for measuring wind speed, wind direction, dew point, temperature and solar radiation. Output from the various sensors was channeled into a translator which conditions the signals and provides an output voltage compatible with the data-logging system. A measure of air turbulence was calculated from time-averaged standard deviations in wind direction.

2) Aerovironmental Model 300 Monostatic Radar - This acoustic sounder measured the turbulent fluctuation of atmospheric temperature on electrosensitive chart paper. A continuous record of the intensity of echo return as a function of height and time is obtained. The instrument has a maximum vertical range of 1000 meters.

3) Warren-Knight Model 84 Double Center Theodolite - Pilot balloons were used in conjunction with this theodolite for monitoring upper-level wind speed and direction. The balloons were of the 30g type and the standard rise rate table was used for computations.

AIRCRAFT DESCRIPTION

A twin engine light aircraft was specially instrumented and used for this study. The aircraft was a Cessna 336 Skymaster owned by Washington State University. This aircraft has a high wing and fixed gear configuration with the engines mounted fore and aft on the fuselage. All probes and sensing devices were mounted on the fuselage or under the wings. (See Figure 2).

Our aircraft was equipped to measure ozone, oxides of nitrogen, condensation nuclei, visual range, temperature, humidity and various navigational parameters. It was also equipped to collect grab samples for subsequent hydrocarbon and halocarbon analysis. Sulfate samples were collected on filters with a TWOMASS sampler developed by Washington University, St. Louis, MO.

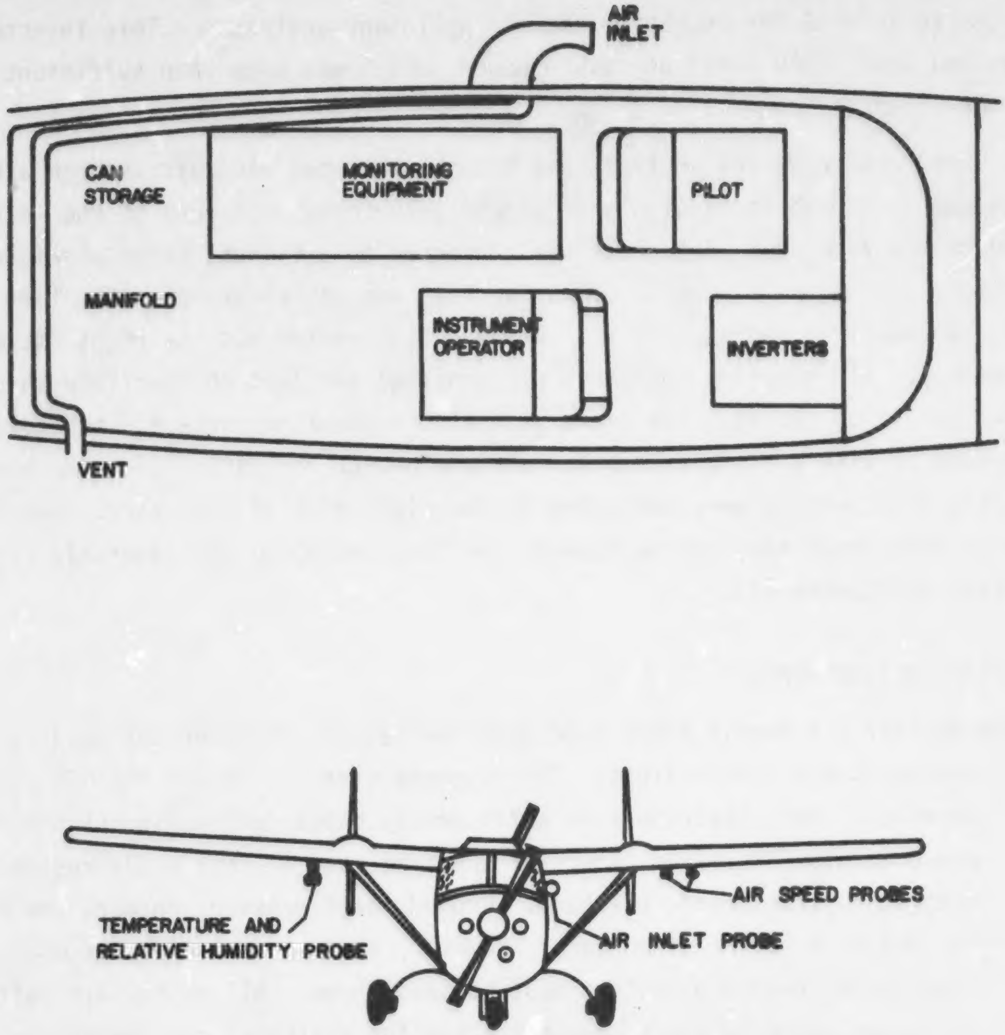
A Topaz solid-state inverter was used to convert the 28-VDC alternator output to 120-VAC for operating the air pollutant analyzers. This inverter provided about 1500 watts of usable power, which was more than sufficient for our needs.

Air to be used for analysis was brought into the aircraft through a 4-inch sampling probe extending approximately 10 inches outboard of the left side of the fuselage. The probe was connected to a 4-inch, clear plexiglass manifold inside the aircraft. This manifold was positioned down the left side of the cabin, across the aft bulkhead, and vented out the right aft cabin window. Air sampling equipment was provided air from the manifold through 1/4-inch Teflon tubing. The large size of the sampling probe and manifold provided us with ample air flow for all equipment. Emissions from the aircraft's front engine were exhausted on the right side of the plane. Detailed checks have shown that engine exhaust and "prop wash" do not adversely effect ambient monitoring (3).

AIRCRAFT MEASUREMENTS

Ozone Monitor - A Bendix Model 8002 Chemiluminescent Analyzer was used to measure ozone levels aloft. The response time ($<$ 10 sec for 90% response) of this instrument is sufficiently rapid for meaningful aircraft measurements. Ozone analyzers of the type used in this study respond to changes in atmospheric pressure. Ground level pressure changes are minor and need not be of concern. However, when an instrument is carried aloft, pressure factors must be considered. All of our aircraft-collected ozone data has been corrected for altitude using equations developed from pressure chamber studies.

Condensation Nuclei - An Environment One Rich 100 Analyzer was used to measure very small particulate material in the atmosphere. This unit responds to particles with diameters of 0.0025 micron and larger and it covers a concentration range of 300 to 10^7 particles per cubic centimeter. Response time for this instrument is 5 sec., which makes it very suitable for airborne measurements.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PILOT
MANIFOLD
INSTRUMENT OPERATOR
INVERTERS
VENT
AIR SPEED PROBES
TEMPERATURE AND RELATIVE HUMIDITY PROBE
AIR INLET PROBE

Figure 2. Diagrams of Cessna aircraft employed in Houston field study.

Nitrogen Oxides - The Monitor Labs Model 8440 Nitrogen Oxides Analyzer was used for the measurement of NO and NO_x. This instrument employs the chemiluminescent reaction of nitric oxide and ozone to measure nitric oxide concentrations. NO_2 is determined by first converting the NO_2 to NO and subsequently measuring the total nitric oxide ($NO + NO_2$) by the chemiluminescent method. The NO_2 concentration is then determined by the difference of ($NO + NO_2$) and NO. This instrument has a separate photomultiplier tube for the NO and NO_x channels, which is important for aircraft work where large distances are covered in a short period of time.

Hydrocarbon and Halocarbon Analysis - Stainless-steel canisters were used for collecting samples for hydrocarbon and halocarbon analysis. All analyses were performed at the ground laboratory shortly after completion of the flight.

Temperature, Relative Humidity and Navigational Parameters - A Metrodata M8 Airborne Meteorological and Navigational System was used to measure temperature, humidity, airspeed, altitude, bearings from two points (VOR) and distance from one point (DME). The temperature and humidity data are derived from sensors mounted under the aircraft wing. The airspeed and altitude systems use potentiometric transducers, which are connected to the aircraft pitot-static system. VOR/DME data are acquired from navigational receivers installed in the aircraft.

Visual Range - A MRI Integrating Nephelometer was used to monitor light scattering and visual range. Air was not dried before entering the analyzer tube so changes in atmospheric humidity must be taken into account when examining these data. The quantitative output of this instrument is given in units of scattering coefficient and meteorological range (visual distance). Sensitivity for scattering coefficient is 0.1 to 100 x $10^{-4}m^{-1}$ and for local visual distance is ∞ to 0.3 miles. We used a flashlamp rate of 16/sec. and an averaging time (time constant) of 0.1 sec.

Sulfate - Samples for sulfate analysis were collected on paliflex filter tapes using a TWOMASS sampler developed at Washington University, St. Louis, MO (4). The analysis was accomplished using a flash vaporizer coupled to a flame photometric sulfur detector (5). The analytical procedure followed is summarized below.

1. 0.25 ml aliquots of distilled water were pipetted into two ml press cap plastic vials. The distilled water contained 0.3 g sulfur per ml and the vials caused no change in this concentration which indicates they are essentially inert to contained sulfur concentrations.

2. 0.6 cm diameter circles were punched from the paliflex filter strips using an ordinary hand punch. These circles represented either the entire sulfate sample spots or filter strip blanks which were punched from the clean areas between the sample spots. These circles were placed in the vials, checked for complete wetting of the paper, and then the vials capped. Extraction of sulfate was accomplished by allowing the vials to stand with occasional shaking for 3 hours or longer.

3. Standard sulfate solutions were prepared from $MgSO_4$ reagent. The stock solution contained 500 μg sulfur per ml. and dilutions of the stock solution were made to provide 20, 4 and 0.8 μg sulfur per ml. standard solutions.

4. The flash vaporizer, Meloy SA-160 sulfur analyzer and HP3380A integrator instrument system was standardized by applying 0.5 and 1.0 μl aliquots of the standards onto the stainless strip of the vaporizer, allowing the distilled water to evaporate, and flashing with a pulse from 0.3 farad charged to 15.3 volts.

5. Similarly, 1.0 and/or 5.0 μl aliquots of the sulfate filter extracts were applied to the vaporizer strip, dried, and flashed. A second flash was always performed following samples and standards to ensure complete vaporization on the first flash (typically 90-98%) and to keep the vaporizer strip clean.

6. The "quantity of sulfur vs. peak area" data for standards were plotted on log-log graph paper and a "best-fit" straight line was drawn through the points for quantities of sulfur greater than two nanograms. A non-linear relationship generally existed for less than two nanograms sulfur.

7. The quantities of sulfur in the sample aliquots were read from the calibration curve and multiplied by 50 or 250 for five or one ml sample aliquots respectively to give the total nanograms of sulfur in the samples. These values were then multiplied by three and divided by 1000 to convert the results to micrograms of sulfate.

   The actual air concentrations measured were calculated by subtracting the blank value from each sample and dividing by the sampled air volume in cubic meters to obtain results in micrograms of sulfate per cubic meter.

DATA HANDLING PROCEDURES

All data collected in the aircraft and from most continuous monitoring ground instruments was recorded on 4-track magnetic tape using Metrodata Model DL620A data logging systems. Output from the gas chromatographs was channeled directly into a Hewlett Packard 3352 data system. This system provided individual hydrocarbon identification and quantitation information immediately following each gc run.

We have developed the software necessary to allow our HP2100 minicomputer (basic component of HP3352 data system) to process 4-track magnetic tape data in the field (6). This permits field personnel to look at nearly a complete data set each day, which is very advantageous from the standpoint of recognizing instrumental manfunctions as well as short term pollutant relationships that warrant further study. The hardware involved in this operation includes a Metrodata Model TR625 tape reader, the Hewlett Packard 2100 computer, a Printec 100 high speed printer and a teletype for communicating with the system. The data processing operation involves converting raw voltages to scientific units, plus time averaging and tabulating for easy review.

The frequency of data recording in the field was dependent on the sampling technique. In the aircraft, where considerable distance was covered in a short time, instrument and sensor responses were recorded five times every two seconds. Under normal flying conditions, this corresponds to a data point approximately every 70 ft. On the ground, where pollutant and meteorological parameters were monitored at a fixed point, data recording times varied from one minute for ozone, oxides of nitrogen and the meteorological sensors to twenty minutes for halocarbons and PAN.

Field data collected on 4-track magnetic tape was transferred to 9-track tape in our home laboratory. This provides a permanent storage mechanism plus a data format that is compatible with Washington State University's IBM-360 computer.

CALIBRATION PROCEDURES

A comprehensive data quality control program is an essential part of all field studies. Instrument calibration and zero checks must be documented so that any questions concerning data quality can be resolved. We kept daily records of these events and have used this information in arriving at the numbers provided in this report. Any data that appeared questionable was not included. A summary of precautions taken to insure data integrity for the various measurements is provided below.

Ozone - The ground based and airborne ozone analyzers were calibrated at least once a week using a McMillan Model 1000 ozone generator. This ozone source was specially designed to provide outputs in the 20 to 200 ppb range. Absolute calibration of the McMillan generator was based on the standard KI method plus spectral measurements using a Dasibi Model 1003-AH ultraviolet ozone photometer.

A zero check was made once a day on the ground ozone instrument. However, in the aircraft numerous checks were made during each flight. The airborne ozone data has been adjusted for zero drift whenever necessary.

EPA Region-VI personnel made two calibration comparisons with our ground ozone instruments during the study period. The ozone concentrations included in this report are based on the EPA calibration. Therefore, our ozone data should be fully consistent with oxidant measurements reported by EPA Region-VI and the local control agencies (Texas Air Control Board and City of Houston).

Oxides of Nitrogen - Our span gas for the TECO and Monitor Labs instruments was a tank containing 1.0 ppm NO. The tank concentration was verified by gas phase titration in our home laboratory. Comprehensive calibration checks were performed in our WSU laboratory before and after the field study. Various nitric oxide concentrations in the .04 to 1.0 ppm range were generated using a Meloy Model CNO20 Nitrogen Oxides/Ozone Calibrator. Both instruments responded in a linear fashion throughout this concentration range. While in the field, a span check was made at least once a week and zero checks were made daily.

Total Hydrocarbon, Methane and Carbon Monoxide - The Beckman 6800 AQGC was calibrated using a tank containing 7.2 ppm C (THC), 2.19 ppm methane and 3.00 ppm carbon monoxide. The hydrocarbon mixture in the calibration tank was standardized relative to hexane. Calibration checks were made about every other day.

Fluorocarbon-11 and Carbon Tetrachloride - The electron capture gas chromatograph was calibrated from standards made up in ambient air. At the present time, we feel this is the best method since the moisture and oxygen content of the standard will be nearly the same as in samples collected during routine analysis periods. The calibration was based on a Freon-11 standard that had been certified by mass spectrometry. Samples from this standard were run daily throughout the study period in order to monitor stability of the electron capture detector. Other halocarbon calibrations were carried out in a similar manner.

Individual Light Hydrocarbons - Identification of the light hydrocarbons (C_2-C_5) was based on retention time comparisons. Resolution of light hydrocarbons on the Durapak n-Octane/Porasil C column was excellent and retention times were extremely reproducible. Thus, little difficulty existed in making unambiguous peak identifications. Calibration of the Perkin Elmer gas chromatographs was achieved by measuring instrument response of known concentrations of hexane in air. Three different hexane sources were used to prepare standards in the ppb range. In the field, an internal standard (neo-Hexane, .209 ppm) was included in each air analysis in order to insure calibration reliability. Higher hydrocarbon (C_6-C_{10}) identities were determined through retention time comparisons with known standards plus mass spectral analysis. Instrument calibration was performed in the same manner as mentioned above for the light hydrocarbons.

Meteorological Parameters - Calibration curves supplied by the manufacturer were used to convert the Climet CI-60 sensor output signals to the appropriate temperature, wind speed, etc., readings. While in the field, sensor signals were checked routinely to insure correct operation.

Particulate Measurements - The condensation nuclei counter and nephelometer were calibrated in our home laboratory prior to going into the field. No calibration checks were made in the field since their primary function was not to provide absolute numbers, but rather to determine gross horizontal and vertical inhomogenities within an air mass. We were concerned only with relative differences.

PAN - PAN calibrations were performed by W. E. Lonneman (EPA - Research Triangle Park). Mr. Lonneman provided and installed the PAN instrument used in this study. The calibration was based on standards prepared in ESRL laboratory at Research Triangle Park, NC.

SECTION 4

RESULTS AND DISCUSSION

A data presentation as well as interpretive discussion follows in this section. The format consists of a number of subsections dealing with specific topics of concern in the Houston area. Subjects that will be discussed include the following:

- Meteorology
- Hydrocarbons
- Oxidants
- Secondary Pollutant Production and Transport
- Oxides of Nitrogen
- Halocarbons
- Visibility and Particles

METEOROLOGY

Rain and cloudiness prevailed in southern Texas during most of July, 1976. Precipitation in Houston was approximately 50% above normal, while some stations in south-central Texas were as much as 500% above normal. Brownsville, Corpus Christi and Del Rio, Texas, recorded their wettest July in history (7). Cooler than normal temperatures accompanied the excessive cloudiness. In the Houston area, temperatures were approximately 3° below normal for July, while farther to the west in the Great Bend country they were about 8° below normal. This unusually wet and cool weather in Texas was associated with weak, slow westward-moving, 700 mb disturbances similar to the monsoon lows of southern Asia.

A brief summary of weather conditions on each day of the study is provided in Table 1. The majority of this information was abstracted from National Weather Service data collected at Houston's Hobby Airport.

HYDROCARBONS

Hydrocarbon measurements included a continuous record of methane and total hydrocarbon levels at the WSU trailer site, plus numerous individual hydrocarbon analyses on samples collected at various locations throughout the Houston area. Samples for detailed hydrocarbon analysis were routinely collected at several sites:

1) WSU Trailer Site - 6 to 9 am integrated sample and afternoon grab sample;
2) North Site - 6 to 9 am integrated sample;
3) South Site - 6 to 9 am integrated sample.

These sampling locations are shown in Figure 1. Grab samples for hydrocarbon analysis were collected at various times during the study period in downtown Houston, Washburn Tunnel and in the industrial area along the Houston ship channel. A large number of samples were also collected by aircraft.

As indicated in the experimental section, individual hydrocarbon identities were established through a comparison of retention times and mass spectrometric fragmentation patterns. Using these procedures, we have been able to identify about 75 hydrocarbon species. This generally corresponds to about 90% of the individual hydrocarbon total. Figure 3 shows a total ion chromatogram obtained from an ambient sample collected in downtown Houston. The numbered peaks were identified as indicated above.

Once a hydrocarbon pattern has been established using the gc-ms technique, it can easily be extrapolated to the large number of field samples since we employ exactly the same column and gas chromatographic conditions in both the field analysis (flame ionization detector) and laboratory analysis (mass spec detector). For example, Figure 4b shows a chromatogram typical of those obtained in the field. The pattern provided by peaks 55, 56 and 58 (ethylbenzene, p & m-xylene and o-xylene) is readily distinguishable in both chromatograms. There are other commonly encountered patterns in the lower molecular weight ranges as well. Using these marker peaks, the low concentration peaks recorded in a field chromatogram can usually be identified.

TABLE 1. METEOROLOGICAL SUMMARY FOR THE JULY 1-25 PERIOD.

Date	Cloud Cover(a)		Surface Wind		5000' Wind(b)		Precipitation			Temperature		Remarks
July	AM	PM	AM	PM	AM	PM	AM	PM	TOTAL	10AM	3PM	
1	.5	.5	SW/8	S/7	---	---	0	0	0	85	91	
2	.5	.4	S/12	S/10	---	---	0	0	0	89	85	PM thunderstorms East-Southeast
3	.5	1.0	S/10	S/15	---	SW/20	.05	2.0	2.05	85	77	light rain in AM thunderstorms in PM
4	1.0	1.0	S/4	S/7	---	SW/4	0	0	0	85	88	ground fog in AM high overcast all day
5	1.0	.8	N/10	NE/7	---	SW/9	T	0	T	75	76	morning thunderstorms
6	.8	1.0	NE/8	SE/10	NE/8	E/14	0	0	0	80	81	visibility 1-5 mi. in haze & smoke during AM
7	1.0	1.0	NE/4	S/10	---	SE/6	0	0	0	83	85	high overcast all day
8	1.0	1.0	E/3	S/3	---	---	0	1.38	1.38	84	86	some breaks in overcast in AM thunderstorms in PM
9	1.0	1.0	NE/5	E/5	---	---	.50	.45	.95	75	76	low clouds-light rain-fog & haze all day
10	1.0	1.0	NE/8	SE/8	---	SE/21	1.91	0	1.91	74	88	low visibility in haze & smoke all day
11	1.0	.8	SE/10	SE/8	---	---	T	0	T	85	85	

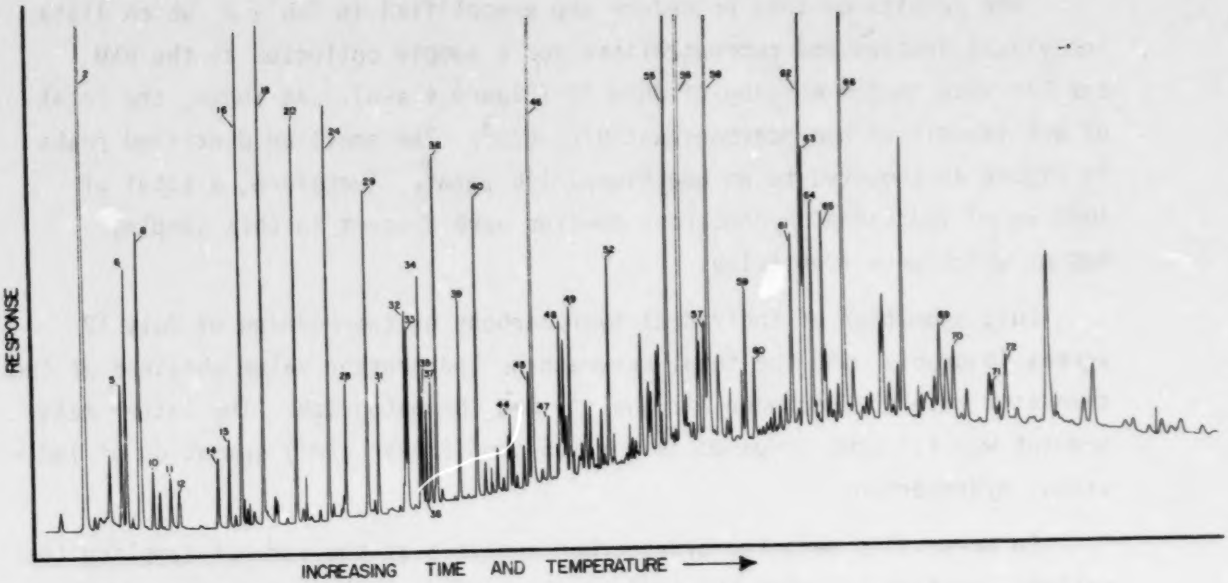
(continued)

TABLE 1. (continued).

Date	Cloud Cover(a)		Surface Wind		5000' Wind(b)		Precipitation			Temperature		Remarks
July	AM	PM	AM	PM	AM	PM	AM	PM	TOTAL	10AM	3PM	
12	1.0	.9	NE/8	SSE/9	E/17	E/14	0	0	0	85	84	
13	.7	.8	S/7	S/10	SW/10	SE/7	0	0	0	85	88	
14	1.0	1.0	NE/6	S/10	S/17	S/20	1.45	0	1.45	76	83	early morning thunderstorms-low visibility with haze & smoke in PM
15	1.0	1.0	S/8	S/5	S/24	S/14	0	0	0	84	87	
16	1.0	1.0	SW/7	SW/5	S/14	SW/16	0	0	0	86	83	isolated thunderstorms in area all day
17	1.0	.8	SW/8	SW/12	SW/12	---	0	0	0	84	90	
18	.9	.8	S/5	S/10	---	---	0	0	0	85	91	evening thunderstorms (5 PM)
19	.5	.6	SW/10	SW/10	S/15	SE/10	0	0	0	88	92	
20	.5	.3	S/10	SW/8	SE/10	SE/14	0	0	0	86	91	
21	.8	.8	E/6	SW/10	---	S/5	.13	0	.13	82	88	early AM thunderstorms
22	.5	.6	E/5	SE/10	---	---	0	0	0	87	92	
23	.8	1.0	calm	SE/10	SE/7	---	0	T	T	86	83	tornados and thunderstorms in PM
24	.3	1.0	NE/10	E/5	E/9	---	0	2.48	2.48	87	92	fog, haze and smoke in AM heavy rain in PM
25	.2	.5	SW/10	SE/8	E/7	SE/4	0	0	0	85	92	reduced visibility in haze & smoke all day

(a) 0 - 1.0 scale

(b) Pibal measurement at WSU trailer



1. 2 - Methyl - 1 - butene
2. 2 - Methylbutane
3. Halocarbon
4. 1 - Pentene
5. 3 - Methyl - 1 - butene
6. n - Pentane
7. Isoprene
8. Carbon disulfide
9. t - 2 - Pentene
10. c - 2 - Pentene
11. 2 - Methyl - 2 - butene
12. 2,2 - Dimethylbutane
13. Cyclopentene
14. (Cyclopentane
    4 - Methyl - 1 - pentene
15. 2,3 - Dimethylbutane
16. (2 - Methylpentane
    t - 4 - Methyl - 2 - pentene
17. c - 4 - Methyl - 2 - pentene
18. 3 - Methylpentane
19. (2 - Methyl - 1 - pentene
    1 Hexene
20. n - Hexane
21. t - 2 - Hexene
22. (2 - Methyl - 2 - pentene
    t - 3 - Methyl - 2 - pentene
23. c - 2 - Hexene
24. Methylcyclopentane
25. c - 3 - Methyl - 2 - pentene
26. 2,2,3 - Trimethylbutane
27. 1,1,1 - Trichloroethane
28. 2,4 - Dimethylpentane
29. Benzene
30. 1 - Methylcyclopentene
31. Cyclohexane
32. 2 - Methylhexane
33. 2,3 - Dimethylpentane
34. 3 - Methylhexane
35. Dimethylcyclopentane
36. Dimethylcyclopentane
37. Dimethylcyclopentane
38. 2,2,3 - Trimethylpentane
39. n - Heptane
40. Methylcyclohexane
41. Trimethylcyclopentane
42. Ethylcyclopentane
43. 2,5 - Dimethylhexane
44. 2,4 - Dimethylhexane
45. 2,3,4 - Trimethylpentane
46. Toluene
47. 2,3 - Dimethylhexane
48. 2 - Methylheptane
49. (3 - Ethylhexane
    3 - Methylheptane
50. C - 9 Alkane
51. Dimethylcyclohexane
52. n - Octane
53. Ethylcyclohexane
54. C - 9 Alkane
55. Ethylbenzene
56. (p - Xylene
    m - Xylene
57. Styrene
58. o - Xylene
59. n - Nonane
60. i - Propylbenzene
61. n - Propylbenzene
62. 3 - Ethyltoluene
63. 2 - Ethyltoluene
64. 1 - Ethyltoluene
65. 1,3,5 - Trimethylbenzene
66. 1,2,4 - Trimethylbenzene
67. 1,2,3 - Trimethylbenzene
68. Methylstyrene
69. 1,3 - Diethylbenzene
70. 1,4 - Diethylbenzene
71. C - 10 Subst'd. benzene
72. C - 10 Subst'd. benzene

Figure 3. Total gas chromatogram for sample collected in Houston.

The results of this procedure are exemplified in Table 2, which lists individual species and concentrations for a sample collected at the WSU trailer site on the morning of July 12 (Figure 4 a-b). As shown, the total of all identified hydrocarbons was 977 $\mu g/m^3$. The small unidentified peaks in Figure 4b amounted to an additional 116 $\mu g/m^3$. Therefore, a total of 1093 $\mu g/m^3$ individual hydrocarbon species were present in this sample, 90% of which were identified.

This summation of individual hydrocarbons on the morning of July 12 agrees favorably with the total non-methane hydrocarbon value obtained at the same time with the Beckmann Air Quality Gas Chromatograph. The latter measurement was 1.4 ppmC compared to the 1.6 ppmC (1093 $\mu g/m^3$) summation of individual hydrocarbons.

In presenting detailed hydrocarbon analyses at the various sampling locations, we have selected the individual species most often present and have displayed these in Tables 3, 4, and 5. It should be recognized that the total concentrations shown in these tables don't include all the individual species identified. Therefore, the total concentration given is somewhat lower than the actual ambient level. The hydrocarbons included in these three tables were considered to be representative of the three hydrocarbon classes (paraffins, olefins and aromatics), and the tables are of convenient size for discussion purposes. The total NMHC concentration obtained by summing the individual species for samples listed in Tables 3, 4, and 5 is provided in Appendix C.

Several features concerning hydrocarbon behavior in the Houston area can be derived from Tables 3, 4, and 5. The 6 to 9 am hydrocarbon total for several days in July at the three sampling sites is shown in Figure 5. Concentrations at the site in south Houston varied between 200 and 900 $\mu g/m^3$, while at the WSU trailer site and in north Houston the ambient concentration exceeded 2000 $\mu g/m^3$ on several mornings. These high levels were most frequently observed at the north site; and consequently, the highest overall average was recorded at that site. Examination of Table 5 shows that on the dates with high hydrocarbon concentration at the north site, aromatic species make-up a majority of the total. For example, Table 6 compares the compositional breakdown on July 16, 17, 19, and 20. July 17 and 19 were mornings when the

TABLE 2. HYDROCARBON LEVELS IN 6-9 AM WSU TRAILER SAMPLE ON JULY 12, 1976.

$\mu g/m^3$	Hydrocarbon	$\mu g/m^3$	Hydrocarbon
22.0	Ethane	8.0	Dimethylcyclopentanes
20.0	Ethylene	15.5	2,2,3-Trimethylpentane
26.0	Acetylene	12.0	n-Heptane
36.0	Propane	10.0	Methylcyclohexane
21.0	Propene	2.0	Ethylcyclopentane
31.5	i-Butane	6.0	2,4-Dimethylhexane
80.0	n-Butane	1.0	2,3,4-Trimethylpentane
6.0	1-Butene	57.0	Toluene
8.0	i-Butene	4.0	2,3-Dimethylhexane
11.0	t-2-Butene	10.5	2-Methylheptane
--	c-2-Butene	8.0	3-Ethylhexane
114	i-Pentane	7.0	C_9-Alkane
55.5	n-Pentane	6.5	n-Octane
4.5	1-Pentene	3.0	Ethylcyclohexane
1.0	t-2-Pentene	5.9	C_9-Alkane
3.0	c-2-Pentene	17.0	Ethylbenzene
5.5	Cyclopentene	40.5	p & m-Xylene
9.0	Cyclopentane	8.0	Styrene
10.5	2,3-Dimethylbutane	19.5	O-Xylene
39.0	2-Methylpentane	6.0	n-Nonane
4.5	c-4-Methyl-2-Pentene	3.0	i-Propylbenzene
21.5	3-Methylpentane	6.5	n-Propylbenzene
4.5	1-Hexene	16.0	p-Ethyltoluene
26.0	n-Hexane	--	m-Ethyltoluene
2.5	t-2-Hexene	8.0	o-Ethyltoluene
4.0	2-Methyl-2-Pentene	8.0	1,3,5-Trimethylbenzene
1.0	c-2-Hexene	18.0	1,2,4-Trimethylbenzene
21.0	Methylcyclopentane	5.0	1,2,3-Trimethylbenzene
7.0	2,4-Dimethylpentane	3.0	Methylstyrene
24.5	Benzene	3.5	1,3-Diethylbenzene
9.0	Cyclohexane	4.0	1,4-Diethylbenzene
23.0	2,3-Dimethylpentane	2.5	C_{10}-Aromatic
23.5	3-Methylhexane	2.5	C_{10}-Aromatic

Total Identified	977
Unknown	116
TOTAL	1093

-- Less than $.5 \mu g/m^3$

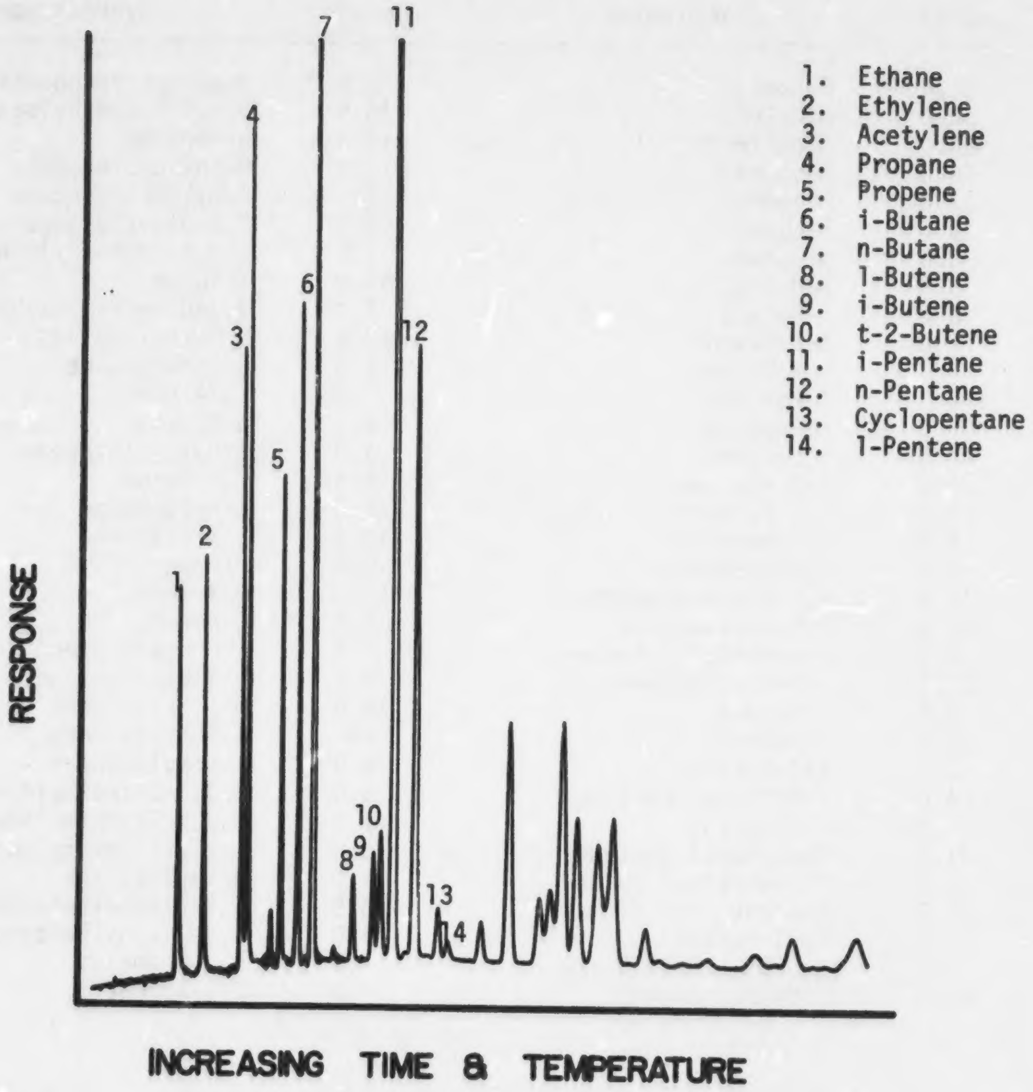


Figure 4a. FID chromatogram for sample collected between 6 and 9 am on July 12 at WSU trailer site(C_2-C_5 analysis).

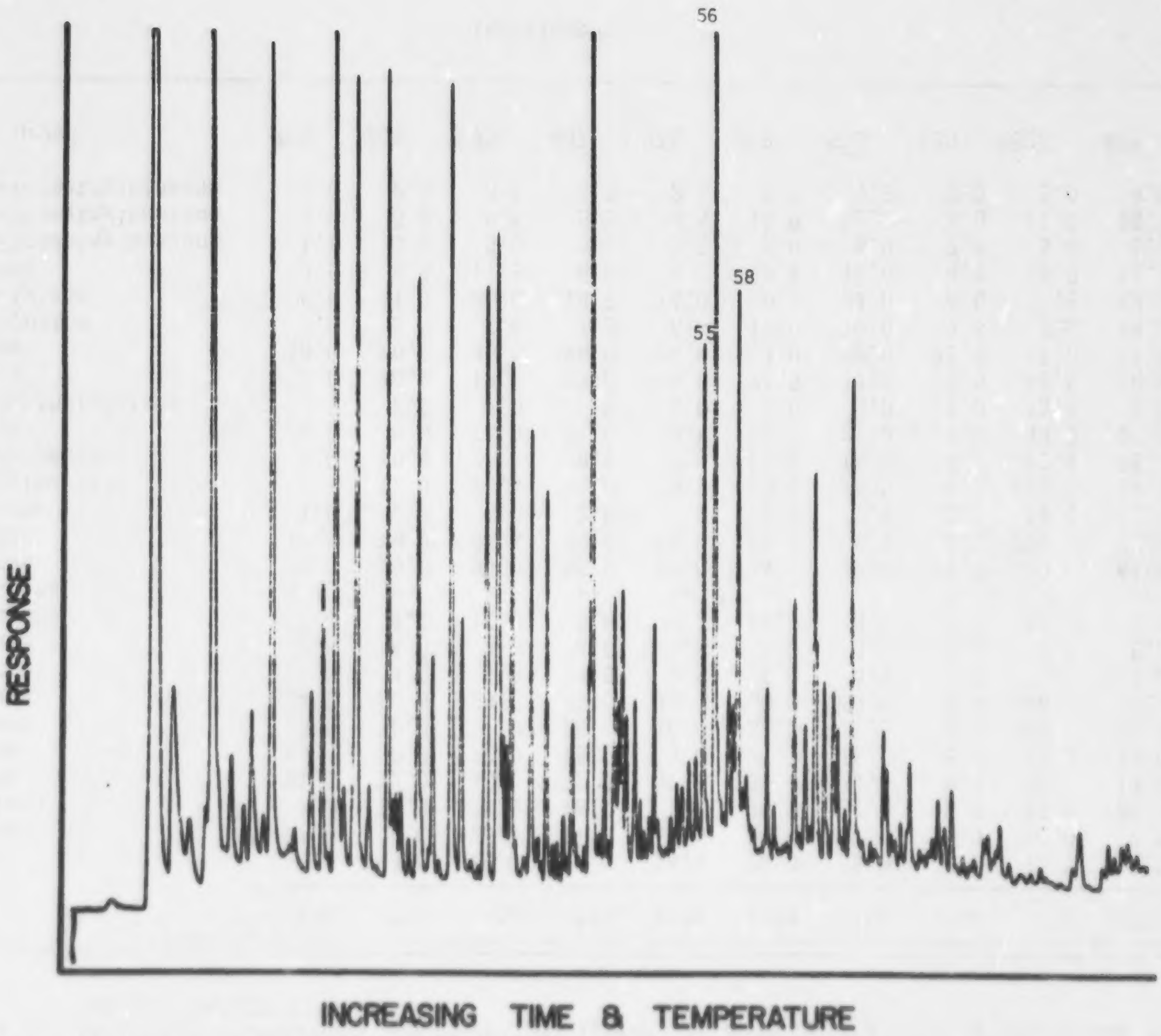


Figure 4b. FID chromatogram for sample collected between 6 and 9 am on July 12 at WSU trailer site (C_5-C_{10} analysis).

TABLE 3. INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED BETWEEN 6 AND 9 AM AT THE WSU TRAILER SITE.

	7/5	7/7	7/8	7/9	7/10	7/12	7/13	7/14	7/15	7/16	7/17
Ethane	14.0	8.0	19.0	18.0	14.0	22.0	25.0	3.0	13.5	6.5	37.0
Ethylene	5.5	6.0	20.0	11.0	12.0	20.0	17.0	5.0	10.0	6.0	12.5
Acetylene	3.0	12.0	20.0	16.0	7.0	26.0	23.0	6.0	13.5	28.0	16.0
Propane	31.0	22.0	46.0	52.0	31.0	36.0	39.0	6.0	28.5	17.0	62.5
Propene	45	10.0	26.0	15.0	9.0	21.0	16.0	5.0	12.0	15.0	16.0
i-Butane	13.0	12.0	51.0	28.0	16.0	31.5	27.5	3.0	205	15.5	38.0
n-Butane	24.5	27.0	69.0	48.0	30.5	80.0	63.5	9.5	846	48.5	68.0
1-Butene	1.0	4.5	6.0	3.0	2.5	6.0	4.5	1.0	10.0	3.0	4.0
i-Butene	2.0	4.0	8.0	4.5	3.0	8.0	6.5	3.0	8.5	5.0	5.0
t-2-Butene	2.0	4.5	10.0	5.5	4.5	11.0	8.0	2.5	24.0	7.0	7.5
c-2-Butene	--	--	--	--	--	--	--	--	--	--	--
i-Pentane	28.5	35.0	90.0	55.5	29.0	114	72.0	15.5	599	61.5	75.5
n-Pentane	14.5	19.0	45.5	30.0	15.0	55.5	36.0	8.0	296	32.0	38.0
1-Pentene	1.0	2.5	6.0	2.5	1.5	4.5	2.5	1.0	19.0	2.0	3.0
2-Methylpentane	7.5	12.0	24.5	14.0	9.5	39.0	24.5	6.5	125	22.5	21.5
3-Methylpentane	6.0	10.5	21.5	9.5	7.5	21.5	15.0	4.0	73.5	15.0	13.0
n-Hexane	6.5	8.0	16.0	11.0	9.5	26.0	21.0	4.0	48.0	20.0	15.0
2,4-Dimethylpentane	1.5	2.0	4.0	2.5	5.0	7.0	5.0	1.0	13.5	5.0	4.0
Benzene	8.0	10.0	18.0	13.0	10.0	24.5	17.5	6.5	42.5	18.5	16.0
Toluene	13.0	20.5	35.0	28.0	23.0	57.0	39.0	12.5	61.0	41.5	32.5
Ethylbenzene	2.5	5.0	7.5	7.0	6.0	17.0	10.0	3.5	13.0	14.0	11.0
p & m-Xylene	6.5	11.0	20.0	14.5	14.0	40.5	27.0	8.5	31.5	33.5	26.0
o-Xylene	3.5	6.5	11.5	6.0	5.0	19.5	12.0	4.5	15.0	15.5	10.0
1,3,5-Trimethylbenzene	1.5	3.0	5.0	3.0	3.5	8.0	6.0	2.5	5.0	6.0	4.0
1,2,4-Trimethylbenzene	3.0	8.0	9.5	6.5	4.5	18.0	12.0	5.5	11.0	18.0	9.0
1,2,3-Trimethylbenzene	1.5	2.0	3.5	2.5	2.5	5.0	3.5	2.0	3.0	4.0	3.5
TOTAL $\mu g/m^3$	206	265	593	407	275	719	533	130	2527	461	549

(continued)

TABLE 3 (continued).

	7/19	7/20	7/21	7/22	7/23	7/24	AVE
Ethane	15.0	12.5	24.5	42.0	68.5	118	27.0
Ethylene	16.0	20.0	19.5	*	*	*	13.0
Acetylene	24.0	23.5	22.0	31.5	19.5	13.0	18.0
Propane	30.0	21.5	48.0	45.0	62.5	621	70.5
Propene	16.0	19.0	15.5	26.0	51.0	82.5	21.0
i-Butane	73.0	16.0	28.0	30.0	36.0	42.0	39.0
n-Butane	313	46.0	69.0	82.5	82.0	65.0	116
1-Butene	6.0	3.5	4.0	1.0	5.0	3.5	4.0
i-Butene	7.5	6.0	6.0	5.0	6.5	4.0	5.5
t-2-Butene	13.5	8.0	7.5	5.0	9.5	5.0	8.0
c-2-Butene	--	--	--	--	--	--	--
i-Pentane	239	63.0	87.0	110	106	74.0	109
n-Pentane	122	31.0	42.5	54.5	51.0	42.5	93.5
1-Pentene	6.0	2.0	2.5	2.0	3.5	2.5	4.0
2-Methylpentane	52.5	22.0	29.0	29.0	9.0	26.5	28.0
3-Methylpentane	32.5	13.0	17.5	20.0	33.0	16.0	19.5
n-Hexane	24.5	14.0	17.0	27.0	20.0	20.5	18.0
2,4-Dimethylpentane	7.0	4.5	5.5	5.0	4.5	14.5	5.5
Benzene	23.0	18.0	20.5	19.0	19.0	19.0	18.0
Toluene	46.0	40.5	49.0	48.5	41.5	32.5	37.5
Ethylbenzene	14.0	12.5	13.0	16.5	14.0	7.5	10.0
p & m-Xylene	35.0	33.5	35.0	40.0	31.5	22.0	25.5
o-Xylene	15.0	14.5	15.0	19.0	14.0	10.0	11.5
1,3,5-Trimethylbenzene	6.0	7.0	1.5	11.5	5.0	4.5	5.0
1,2,4-Trimethylbenzene	12.5	30.0	14.0	19.5	12.0	8.0	12.0
1,2,3-Trimethylbenzene	4.0	6.5	2.0	7.0	4.5	3.0	3.5
TOTAL µg/m^3	1153	488	595	697	709	1257	723

-- Less than .5µg/m^3

* Value questionable or no data

TABLE 4. INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED BETWEEN 6 AND 9 AM AT THE SOUTH SITE.

	7/9	7/10	7/12	7/13	7/14	7/15	7/16
Ethane	18.0	9.0	10.0	73.0	18.0	21.0	7.5
Ethylene	59.0	24.5	19.5	126	24.5	33.5	39.5
Acetylene	32.0	2.0	4.0	26.5	15.0	7.0	4.0
Propane	91.0	16.5	21.5	110	50.0	32.5	14.5
Propene	145.0	8.5	6.5	13.5	17.5	4.5	4.0
i-Butane	148.0	8.5	18.0	49.5	46.5	15.5	7.5
n-Butane	64.5	11.5	24.5	60.0	79.0	24.0	14.0
1-Butene	5.0	1.0	1.0	4.0	6.0	1.5	1.0
i-Butene	8.5	1.5	2.0	5.0	6.0	2.5	2.5
t-2-Butene	4.0	1.0	1.0	--	12.0	2.0	1.5
c-2-Butene	--	--	--	--	--	--	--
i-Pentane	77.0	12.0	23.0	49.0	76.5	22.0	14.0
n-Pentane	85.5	6.5	12.5	34.0	40.5	13.0	11.0
1-Pentene	2.0	--	1.0	2.0	4.0	1.5	1.0
2-Methylpentane	17.0	4.0	6.0	20.0	23.0	7.0	5.0
3-Methylpentane	11.0	3.0	5.0	12.0	14.5	5.0	5.0
n-Hexane	18.0	13.0	9.0	16.0	21.0	5.0	18.5
2,4-Dimethylpentane	7.0	--	*	3.0	3.5	1.5	--
Benzene	16.5	6.5	*	14.0	23.5	5.5	5.0
Toluene	31.5	13.5	*	29.0	39.0	15.5	12.0
Ethylbenzene	12.0	2.5	*	9.0	15.0	5.5	3.5
p & m-Xylene	21.0	4.0	*	21.0	33.0	8.0	6.0
o-Xylene	7.0	3.0	*	10.5	14.5	4.5	3.0
1,3,5-Trimethylbenzene	2.5	2.0	*	5.0	5.5	2.0	2.0
1,2,4-Trimethylbenzene	3.5	2.0	*	18.0	8.0	4.0	5.0
1,2,3-Trimethylbenzene	2.0	1.5	*	3.5	5.0	--	1.5
TOTAL $\mu g/m^3$	889	158	--	714	601	244	193

(continued)

TABLE 4 (continued).

	7/17	7/19	7/20	7/21	7/22	AVE
Ethane	33.0	3.5	9.0	10.0	5.0	18.0
Ethylene	10.5	7.5	13.0	18.0	34.0	34.0
Acetylene	6.0	3.5	4.5	8.5	8.0	10.0
Propane	40.5	3.5	17.0	10.5	80.5	40.5
Propene	5.5	3.0	5.5	7.0	8.5	19.0
i-Butane	18.0	2.5	24.5	8.5	32.0	32.0
n-Butane	31.0	13.5	21.0	18.5	57.0	34.5
1-Butene	1.5	1.0	1.0	1.5	3.0	2.5
i-Butene	1.5	2.0	2.5	5.0	3.0	3.5
t-2-Butene	2.5	--	--	7.5	7.0	3.5
c-2-Butene	--	--	--	--	--	--
i-Pentane	30.0	12.5	14.0	25.0	55.0	37.0
n-Pentane	17.5	11.0	10.0	14.0	28.5	26.0
1-Pentene	1.0	--	--	1.5	1.0	1.5
2-Methylpentane	9.5	4.0	4.0	11.0	7.0	10.0
3-Methylpentane	6.0	3.0	3.0	7.0	16.0	7.5
n-Hexane	9.0	9.5	6.5	23.5	11.0	13.0
2,4-Dimethylpentane	2.0	--	2.0	*	3.0	2.5
Benzene	7.5	5.5	7.0	*	12.5	10.5
Toluene	17.5	24.0	10.0	*	30.0	22.0
Ethylbenzene	3.0	36.0	3.0	*	10.0	10.0
p & m-Xylene	10.0	137	4.5	*	18.0	26.5
o-Xylene	3.0	80.0	5.0	*	10.0	14.0
1,3,5-Trimethylbenzene	3.0	19.0	2.0	*	5.0	5.0
1,2,4-Trimethylbenzene	4.5	258	8.5	*	12.5	32.5
1,2,3-Trimethylbenzene	1.5	37.0	1.5	*	3.5	5.5
Total μg/m^3	275	677	179	--	461	421

-- Less than .5 μg/m^3
* Value questionable or no data

TABLE 5. INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED BETWEEN 6 AND 9 AM AT THE NORTH SITE.

	7/9	7/10	7/12	7/14	7/15	7/16
Ethane	17.5	18.0	8.0	6.0	17.5	17.5
Ethylene	15.0	10.0	5.0	11.5	9.5	14.0
Acetylene	5.0	3.5	1.5	3.0	6.5	9.0
Propane	34.0	58.0	10.0	7.5	27.0	38.0
Propene	7.0	8.5	2.0	2.5	6.0	9.5
i-Butane	17.0	27.0	6.5	4.0	20.5	26.0
n-Butane	30.5	39.0	12.0	7.5	49.0	64.0
1-Butene	2.0	3.0	1.0	1.0	2.0	3.0
i-Butene	2.5	2.5	1.0	2.0	3.0	4.0
t-2-Butene	2.5	3.0	1.0	1.0	3.0	5.5
c-2-Butene	--	--	--	--	--	--
i-Pentane	30.5	28.5	9.0	10.0	43.0	65.0
n-Pentane	17.5	19.0	4.5	6.5	21.5	32.0
1-Pentene	1.0	1.5	1.0	--	2.0	2.5
2-Methylpentane	8.5	8.5	3.0	3.5	12.0	19.0
3-Methylpentane	5.5	5.5	2.0	2.0	8.5	12.0
n-Hexane	7.0	12.0	5.0	3.0	9.5	13.0
2,4-Dimethylpentane	2.5	2.5	--	.5	*	4.0
Benzene	8.0	8.0	4.0	4.0	*	14.0
Toluene	27.0	21.5	51.0	13.0	*	42.0
Ethylbenzene	4.5	5.0	53.0	3.0	*	3.5
p & m-Xylene	12.5	7.0	206	12.0	*	20.5
o-Xylene	5.5	4.5	113	5.0	*	2.0
1,3,5-Trimethylbenzene	3.0	3.0	74	2.0	*	4.0
1,2,4-Trimethylbenzene	5.0	4.0	308	7.5	*	12.0
1,2,3-Trimethylbenzene	8.5	4.5	69	2.0	*	4.0
TOTAL $\mu g/m^3$	280	308	951	120	--	440

(continued)

TABLE 5 (continued).

	7/17	7/19	7/20	7/21	AVE
Ethane	33.0	14.5	22.0	25.0	18.0
Ethylene	10.5	16.0	19.0	23.0	13.5
Acetylene	6.0	9.5	8.0	10.0	6.0
Propane	40.5	45.0	40.5	43.5	34.5
Propene	6.0	11.0	9.0	13.0	7.5
i-Butane	18.0	31.0	21.0	33.0	20.5
n-Butane	31.0	47.0	40.0	48.0	37.0
1-Butene	1.5	2.5	2.0	3.0	2.0
i-Butene	2.5	4.0	3.5	3.5	3.0
t-2-Butene	2.5	4.0	3.5	3.0	3.0
c-2-Butene	--	--	--	--	--
i-Pentane	30.0	42.0	41.0	45.0	34.5
n-Pentane	18.0	23.0	22.0	27.5	19.0
1-Pentene	1.0	2.5	2.0	2.5	1.5
2-Methylpentane	10.0	21.0	14.5	23.0	12.5
3-Methylpentane	6.0	12.5	13.5	14.0	8.0
n-Hexane	9.0	25.0	15.0	28.0	12.5
2,4-Dimethylpentane	3.0	3.0	2.0	3.0	2.5
Benzene	14.0	13.0	11.0	14.0	10.0
Toluene	140	173	28.0	140	70.5
Ethylbenzene	158	224	7.0	158	68.5
p & m-Xylene	484	778	23.0	484	225
o-Xylene	385	161	10.5	385	119
1,3,5-Trimethylbenzene	199	975	4.0	199	163
1,2,4-Trimethylbenzene	522	224	12.5	522	180
1,2,3-Trimethylbenzene	125	31.0	5.0	125	41.5
TOTAL µg/m³	2256	2893	376	2375	1110

-- Less than .5µg/m³
* Value questionable or no data

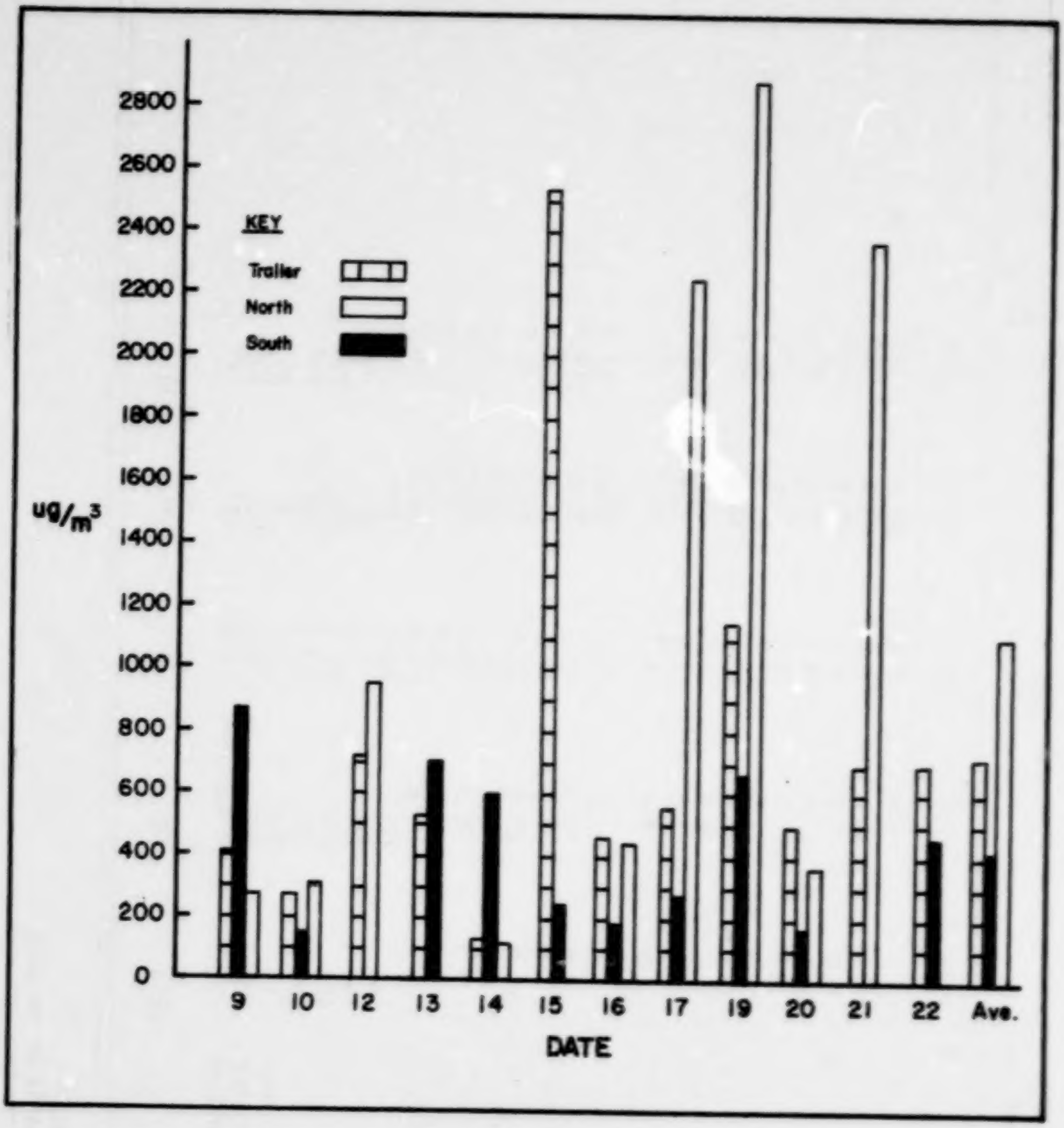


Figure 5. Summary of 6-9 am hydrocarbon data obtained at the three Houston area ground sampling sites.

hydrocarbon concentration was exceptionally high at the north site. It can be seen seen that about 90% of the hydrocarbon burden was comprised of aromatics on these mornings. On the 16th and 20th, when total concentrations were lower and more comparable between the north site and WSU trailer site, a more normal distribution of aromatics, paraffins and olefins was observed. On July 19 the total hydrocarbon level was also quite high at the WSU trailer site; however, the compositional breakdown is very different when compared with the north site. At the trailer site, paraffinic species are by far the most abundant. The complexity of Houston's hydrocarbon sources is exemplified by the fact that two sampling sites approximately 10 miles apart can exhibit very different compositional patterns.

Afternoon average ambient hydrocarbon levels at the WSU trailer site were about a factor of three lower than during the 6-9 am period. With the exception of the most photochemically reactive olefins, the hydrocarbon to acetylene ratios didn't vary much between morning and afternoon. Also, the percentage of olefins, aromatics and paraffins is comparable during both periods of the day at the site in northwest Houston. This indicates that the same emission sources contribute to the morning and afternoon hydrocarbon burden in this section of Houston. Table 7 provides a summary of hydrocarbon analyses on samples collected during afternoon hours at the WSU trailer site.

The average ethylene/acetylene ratios differ between the three hydrocarbon sampling sites. The daily ratio at the WSU trailer was generally less than one with an average value of .72. The ethylene/acetylene ratios at the north and south sites were 2.3 and 3.4 respectively. The lower value observed at the trailer site in northwest Houston indicates a higher automotive contribution at that site. Grab samples that were collected in downtown Houston at high density traffic locations consistently exhibited an ethylene/acetylene ratio less than one.

The identification of hydrocarbon source contributions is important in the Houston area if proper control strategies are to be devised. Several research groups have addressed this problem. In 1973, Lonneman and Bufalini (8) reported the results from a one-day program in which samples were collected at various urban, industrial, tunnel and rural locations in the Houston vicinity. Estimates of vehicular hydrocarbons at the different

TABLE 6. HYDROCARBON COMPOSITION COMPARISON AT TWO SITES BETWEEN 6 AND 9 am ON JULY 16, 17, 19 and 20, 1976.

	North Site	WSU Trailer Site
7/16/76		
Total μg/m^3	440	461
% aromatic	23	32
% paraffin	69	60
% olefin	8	8
7/17/76		
Total μg/m^3	2256	549
% aromatic	90	20
% paraffin	9	72
% olefin	1	8
7/19/76		
Total μg/m^3	2893	1153
% aromatic	89	13
% paraffin	10	81
% olefin	1	6
7/20/76		
Total μg/m^3	375	488
% aromatic	27	33
% paraffin	63	55
% olefin	10	12

sites were made by comparing certain hydrocarbon/acetylene ratios with those obtained in tunnel samples. The latter was assumed to be a valid representation of pure automobile emissions. A significant contribution from non-vehicular hydrocarbon sources was observed at most of the sampling sites. At some of the locations, as little as 10-15% of the hydrocarbon burden could

TABLE 7. INDIVIDUAL HYDROCARBON CONCENTRATIONS (μg/m^3) IN SAMPLES COLLECTED DURING THE AFTERNOON HOURS AT THE WSU TRAILER SITE.

	7/6 G-2	7/9 G-4	7/10 G-4	7/12 G-4	7/13 G-4	7/14 G-4	7/15 G-4	7/17 G-4	7/21 G-4	AVE
Ethane	5.0	6.0	3.5	11.5	4.0	9.0	4.0	5.0	8.0	6.0
Ethylene	3.0	--	4.5	7.5	4.0	9.0	5.0	3.5	14.0	5.5
Acetylene	2.5	8.0	11.0	7.0	3.0	9.0	9.5	2.0	16.5	7.5
Propane	9.5	14.0	18.5	41.5	5.5	19.0	10.0	4.5	20.5	16.0
Propene	2.0	10.5	9.0	11.5	2.0	6.0	5.0	1.5	24.5	8.0
i-Butane	5.0	14.0	14.0	42.0	4.0	17.0	9.5	2.5	33.5	15.5
n-Butane	10.0	34.0	24.5	37.5	13.0	35.5	34.5	6.0	82.0	31.0
1-Butene	--	2.0	1.0	2.0	--	2.0	1.5	1.5	4.0	1.5
i-Butene	1.5	4.0	2.0	3.0	2.0	2.5	2.5	--	12.0	3.5
t-2-Butene	1.0	--	--	1.5	1.0	2.0	2.5	--	13.5	2.5
c-2-Butene	--	--	3.0	--	--	--	--	--	--	1.0
i-Pentane	11.0	53.0	32.0	39.0	15.0	37.0	37.5	8.0	79.0	31.0
n-Pentane	5.5	23.5	15.5	21.5	8.0	20.0	19.5	5.5	44.0	19.5
1-Pentene	--	2.0	--	4.0	1.0	2.5	1.5	--	3.0	3.5
2-Methylpentane	3.0	16.0	2.5	11.5	4.0	14.0	10.5	2.5	6.5	8.0
3-Methylpentane	2.0	10.0	3.0	7.0	3.0	13.0	6.5	1.5	28.0	8.0
n-Hexane	2.5	9.5	6.5	11.5	3.5	24.5	8.5	4.0	23.0	10.5
2,4-Dimethylpentane	2.0	2.0	1.5	2.0	1.0	1.5	2.5	--	2.0	1.5
Benzene	5.5	10.5	10.0	11.0	5.5	12.0	9.5	4.0	9.0	8.5
Toluene	4.0	24.0	20.0	15.5	8.5	18.5	20.0	6.0	15.5	14.5
Ethylbenzene	1.0	6.5	7.0	9.0	3.0	9.0	11.0	3.5	8.5	6.5
p & m-Xylene	3.0	14.0	11.0	11.0	4.0	13.5	22.0	4.0	21.0	11.5
o-Xylene	2.0	6.0	5.5	7.0	3.0	6.0	8.5	3.0	5.5	5.0
1,3,5-Trimethylbenzene	1.5	2.5	2.5	3.0	2.5	2.5	4.0	2.0	7.5	3.0
1,2,4-Trimethylbenzene	6.0	7.0	6.0	4.0	3.0	3.0	8.0	3.0	20.0	6.5
1,2,3-Trimethylbenzene	1.0	1.5	1.5	2.0	--	2.0	2.5	1.0	3.0	1.5
TOTAL μg/m^3	89.5	280.5	221.0	324.0	103.5	290.0	256.0	74.5	504.0	238.0

-- Less than .5μg/m^3

be attributed to vehicular sources. In their sample considered to be most representative of vehicular and industrial emissions emanating from the city, approximately 50% of the total hydrocarbons could be attributed to vehicular sources.

A more extensive study was conducted in 1975 by Texas Air Control Board (TACB) personnel (9). They used the Lonneman method of ratioing to arrive at the automotive contribution at three Houston area sites. The TACB study included a larger data base and, in addition, considerable effort was put into arriving at hydrocarbon/acetylene ratios truly representative of automotive emissions in the Houston area. As would be expected, they found the vehicular component of the ambient C_2-C_5 hydrocarbon mixture to always be greater in downtown Houston than in the adjacent industrial area. However, they showed that the majority of the C_2-C_5 hydrocarbon burden in both areas was derived from nonvehicular sources. This was even the case during the early morning traffic rush period. Table 8 summarizes the average vehicular component during various periods of the day at two Houston locations. It is evident from this table that vehicular hydrocarbons usually comprise less than 40% of the downtown hydrocarbon burden and less than 20% in the industrial region. These findings agree with the earlier work conducted by Lonneman and Bufalini (8).

TABLE 8. AVERAGE VEHICULAR COMPONENT BASED ON C_2-C_5 HYDROCARBONS AT TWO HOUSTON LOCATIONS (9)

Time	Downtown	Jacinto City
0500-0600	23%	15%
0730-0830	45%	34%
1000-1100	35%	11%
1200-1300	24%	12%
1500-1600	29%	15%
1630-1730	34%	12%

A third attempt to relate hydrocarbon composition to emission sources in the Houston area has been reported recently (10). Specific vehicular-industrial hydrocarbon breakdowns were not reported in this latter study; however, it was concluded that both automobile and industrial processes are important to the hydrocarbon problem in Houston. The University of Houston group further concludes that in the downtown area automobiles do contribute more to the pollution burden, as the frequency of olefins has been found to be greater than at sites in the industrial area.

By using the ratioing technique, we have derived source contributions from data we collected during July 1976. We have used the vehicular hydrocarbon/acetylene ratios derived in the TACB study. These appear to have been carefully established from a much better data base than we possess. Table 9 shows the average vehicular percentage based on C_2-C_5 hydrocarbons during the 0600-0900 time period at our three sampling sites. The vehicular component varies between 25 to 31%. Thus, these results support the contention that

TABLE 9. AVERAGE VEHICULAR CONTRIBUTION AT THREE HOUSTON AREA SAMPLING SITES.

	WSU Trailer	North Site	South Site
Average C_2-C_5 Hydrocarbons ($\mu g/m^3$)	505	191	252
Average Acetylene ($\mu g/m^3$)	18	6	10
C_2-C_5/Acetylene	28.1	31.8	25.2
C_2-C_5/Acetylene from vehicular source †	8.0	8.0	8.0
% Vehicular contribution to C_2-C_5 hydrocarbon total	29	25	31

† The C_2-C_5/Acetylene ratio of 8.0 was taken from reference 9. We collected three samples during the July field program in areas that should be dominated by automotive emissions. The average C_2-C_5/Acetylene ratio in the three samples was 8.3.

hydrocarbons derived from non-automotive sources are the major constituent of the Houston atmosphere even during the 0600-0900 peak traffic period.

It should be emphasized that the vehicular percentages derived in Table 9 were based on the C_2-C_5 hydrocarbons only. This probably results in an upper limit value at most of the sites. This is especially true at the north site, where the abnormally high aromatic content implies an even greater industrial contribution. In other words, if the entire C_2-C_{10} hydrocarbon spectrum had been considered, the automotive contribution at the north site would be considerably less than 25%.*

It is obvious from Tables 3, 4 and 5 that the NAAQS for hydrocarbons of 160 $\mu g/m^3$ (.24 ppmC) was exceeded on nearly every morning at the three sampling sites. We feel that the hydrocarbon burden measured at the three sites results primarily from emission sources in the area between Baytown and the western fringes of Houston. Table 10 provides a comparison of the average 0600 to 0900 ambient hydrocarbon concentrations at the urban sites with the average concentration obtained from samples collected to the east of the Baytown industrial area. These latter samples were collected during periods of easterly or southeasterly winds and are considered to be representative of background air entering the Houston area at various times throughout the study period.

TABLE 10. COMPARISON OF HOUSTON AREA HYDROCARBON CONCENTRATIONS

	Trailer	North	South	Background Air	High O_3 Air
Average Hydrocarbon Concentration μg/m	723	1110	421	41.5	206

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* Lonneman obtained a $\Sigma_{aromatics}/C_2H_2$ ratio of 4.3 for automobile emissions in the 1973 Houston study. If this factor was compared with our average numbers $\Sigma_{aromatics}/C_2H_2 = 878/6 = 146$, less than 3% of the average hydrocarbon burden at the north site would be due to vehicular sources.

It is clear from this table that, on the average, a minimum of a 10 fold enhancement in hydrocarbon concentrations was recorded in the Houston urban-industrial area. The category listed as "High O_3" in Table 10 was included to provide an indication of hydrocarbon concentrations in air masses with an ozone concentration greater than 80 ppb. All of the samples included in the "High O_3" category were collected below 4000' by aircraft. Some of these were directly over the Houston urban-industrial area, while others were collected in the downwind plume. The 206 $\mu g/m^3$ average hydrocarbon burden is less than the ground level 0600-0900 am averages; however, it is significantly larger than hydrocarbon concentrations in the background air.

Tables 11 & 12 provide a detailed summary of the samples considered in the "Background Air" and "High O_3" classifications. The A coding above the date refers to an aircraft collected sample for which the collection location and times can be found in the Appendix.

It is difficult to group the aircraft hydrocarbon data in distinct categories for discussion purposes because samples were never collected in the same location. The two exceptions are the classifications provided in Tables 11 & 12, which represent "background air" and polluted air masses (High O_3). Since the latter class consists entirely of samples collected in the urban plume, it is interesting to compare the average vehicular content of the airborne plume with that observed at ground level. Using a C_2-C_5/acetylene ratioing procedure identical to that shown in Table 9, the vehicular content of the aircraft collected plume samples was 25%. This is about the same as the 29, 25 and 31% values obtained at the three ground stations.

OXIDANTS

Ozone

A large ozone data base exists for the Southeastern Texas region due to the monitoring efforts of the Texas Air Control Board and City of Houston. Ozone trends in the Houston area for the period 1974-76 have been reviewed by Gise (11). Table 13 shows that ozone levels have exhibited an increasing trend during the three-year period. This is in spite of the fact that hydrocarbon emissions were reduced by an estimated 40% during the same period (2).

TABLE 11. INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES CONSIDERED TO BE REPRESENTATIVE OF BACKGROUND AIR.

	A-1 7/7	A-1 7/12	A-1 7/14	A-1 7/20	Ground Level 20 mi E of Baytown 7/4/76	AVE
Ethane	3.0	4.5	3.0	10.5	2.5	4.5
Ethylene		1.0	2.0	3.0	2.0	2.0
Acetylene	--	--	--	--	--	--
Propane	2.5	4.5	4.0	9.5	1.5	4.5
Propene	1.0	1.0	1.0	2.0	--	1.0
i-Butane	1.0	2.0	2.0	4.0	1.0	2.0
n-Butane	1.0	2.5	3.5	4.5	2.0	2.5
1-Butene	--	--	--	--	--	--
i-Butene	--	--	--	--	--	--
t-2-Butene	--	--	--	--	--	--
c-2-Butene	--	--	--	--	--	--
i-Pentane	1.5	2.0	4.0	3.0	2.5	2.5
n-Pentane	1.0	2.5	3.5	2.0	1.0	2.0
1-Pentene	--	1.0	--		--	--
2-Methylpentane	4.0	--	--	1.0	4.0	2.0
3-Methylpentane	1.5	1.5	2.0	2.0	3.0	2.0
n-Hexane	1.0	1.0	--	1.0	3.5	1.5
2,4-Dimethylpentane	--	--	--	1.0	3.0	1.0
Benzene	2.0	2.5	2.5	3.0	3.0	2.5
Toluene	5.0	2.0	2.5	8.0	1.5	4.0
Ethylbenzene	1.5		2.0	2.0	1.0	1.5
p & m-Xylene	1.5	1.0	1.5	1.0	1.0	1.0
o-Xylene	1.0	1.5	2.0	1.5	1.0	1.5
1,3,5-Trimethylbenzene	1.0	2.5	1.5	1.0	1.0	1.5
1,2,4-Trimethylbenzene	1.0	2.0	3.0	1.0	1.5	1.5
1,2,3-Trimethylbenzene	1.0	1.0	--	--	1.0	.5
TOTAL $\mu g/m^3$	31.5	36.0	40.0	61.0	37.0	41.5

-- Less than $.5 \mu g/m^3$
* Value questionable

TABLE 12. INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED IN AIR MASSES CONTAINING OZONE LEVELS GREATER THAN 80 PPB.

	A-4 7/7	A-3 7/8	A-1 7/10	A-2 7/10	A-3 7/12	A-4 7/12	A-2 7/14
Ethane	16.0	8.5	11.0	13.0	47.0	14.0	13.0
Ethylene	14.0		16.5	15.0	15.0		10.0
Acetylene	9.0	6.5	4.0	5.0	3.0	5.0	5.0
Propane	55.0	28.5	19.0	26.5	25.5	27.0	22.0
Propene	19.0	3.0	3.5	5.0	8.5	1.5	2.5
i-Butane	50.0	25.0	55.0	21.0	13.5	20.5	22.0
n-Butane	61.0	24.5	13.5	27.5	12.0	20.0	21.5
1-Butene	5.5	1.0	1.5	1.5	1.0	1.0	1.0
i-Butene	3.5	1.5	1.5	1.5	1.5	2.0	1.5
t-2-Butene	4.0	1.0	--	--	--	--	--
c-2-Butene	--	--	--	--	--	--	--
i-Pentane	48.0	21.5	10.5	24.5	9.5	17.0	18.5
n-Pentane	27.0	13.0	12.0	14.5	6.0	10.0	10.5
1-Pentene	2.0	3.0	1.0	1.0	2.0	1.5	1.0
2-Methylpentane	12.0	6.5	4.5	7.5	3.0	6.0	6.0
3-Methylpentane	11.5	5.0	3.5	8.0	5.0	4.0	6.5
n-Hexane	16.0	7.0	9.0	7.5	2.0	4.5	6.5
2,4-Dimethylpentane	2.0	1.0	--	1.0	--	1.0	1.0
Benzene	23.0	10.0	6.5	10.0	5.0	8.5	7.5
Toluene	22.0	11.5	7.0	13.0	3.5	9.0	7.0
Ethylbenzene	6.0	3.0	1.5	4.0	2.0	5.0	3.0
p & m-Xylene	14.0	4.0	2.5	6.0	2.0	8.5	2.5
o-Xylene	6.0	3.0	2.5	4.0	1.5	4.0	2.0
1,3,5-Trimethylbenzene	3.0	2.0	1.5	1.5	2.0	2.0	1.5
1,2,4-Trimethylbenzene	4.0	1.5	1.0	3.0	1.0	4.0	2.5
1,2,3-Trimethylbenzene	--	1.0	1.0	1.5	1.0	3.0	--
TOTAL $\mu g/m^3$	434	193	190	223	173	179	175

(continued)

TABLE 12 (continued).

	A-3 7/14	A-1 7/18	A-2 7/20	A-3 7/20	A-6 7/22	AVE
Ethane	12.0	11.0	11.0	8.5	34.0	16.5
Ethylene	9.5	4.0	7.5	5.0	*	10.5
Acetylene	9.0	1.0	2.5	1.0	1.5	4.5
Propane	26.5	18.5	19.0	15.0	22.0	25.5
Propene	5.0	1.0	2.5	2.0	6.0	5.0
i-Butane	22.5	10.0	15.5	13.0	17.5	24.0
n-Butane	37.5	15.5	30.0	14.0	19.0	24.5
1-Butene	1.5	--	1.0	--	--	1.5
i-Butene	2.5	1.0	1.5	1.5	1.5	2.0
t-2-Butene	1.0	--	--	--	--	.5
c-2-Butene	--	--	--	--	--	--
i-Pentane	35.5	12.5	25.5	14.5	13.5	21.0
n-Pentane	20.5	7.5	12.5	10.5	10.0	13.0
1-Pentene	--	2.5	1.0	--	--	1.5
2-Methylpentane	10.0	5.0	5.0	4.5	4.0	6.0
3-Methylpentane	10.5	2.5	8.0	5.5	2.5	6.0
n-Hexane	8.5	--	6.0	4.5	3.0	6.0
2,4-Dimethylpentane	1.5	2.0	1.0	--	--	1.0
Benzene	11.0	9.5	7.5	4.0	6.0	9.0
Toluene	17.5	5.5	8.5	4.0	5.0	9.5
Ethylbenzene	6.0	2.0	3.5	2.0	2.0	3.5
p & m-Xylene	9.5	1.5	4.0	2.0	2.0	5.0
o-Xylene	5.0	2.0	4.5	3.5	1.5	3.5
1,3,5-Trimethylbenzene	2.5	1.5	2.5	2.0	2.0	2.0
1,2,4-Trimethylbenzene	2.0	3.0	4.5	3.5	2.5	2.5
1,2,3-Trimethylbenzene	3.0	1.0	--	--	4.0	1.5
TOTAL μg/m^3	270	120	185	121	160	206

-- Less than .5μg/m^3

* Value questionable

Analysis of ambient air quality data in the Houston area indicates that little relationship exists between ambient hydrocarbon levels and ozone concentrations (12). Additional studies have shown that meteorology is an important factor since most ozone episodes occur when weak pressure gradients prevail (13). Also, it has been pointed out that a type of "blanket" ozone effect commonly exists in Texas with many stations in widely distributed areas exceeding the .08 ppm standard at the same time.

TABLE 13. ANNUAL STATISTICS FOR OZONE IN THE HOUSTON AREA, 1975-1976 (11).

	Aldine (North Site)			Houston (TACB Site)		
	1974	1975	1976	1974	1975	1976
Number of Hours > .08 ppm	83	251	397	213	202	279
Percent of Hours > .08 ppm	3.4	4.2	7.7	3.0	3.7	4.2
Percent of Days > .08 ppm	24.3	25.4	41.5	20.7	22.7	24.4
Number of Hours > .12 ppm	13.	67.	90.	55.	56.	62.
Number of Hours > .16 ppm	3.	14.	24.	8.	16.	27.

The relative importance of ozone and/or ozone precursor transport into the Houston area vs. ozone production from locally emitted precursors has not been well established. Data collected by WSU during July, 1976, is valuable from this standpoint since synoptic scale transport was minimal during this period. Between July 1 and 24, 1976, there were no "blanket" ozone episodes in southern Texas. We believe that secondary pollutants measured in the Houston area during July, 1976, resulted from precursors emitted in the immediate Houston area. Thus, one of the unique features of these data is that they provided a basis for establishing Houston's potential for generating oxidants.

TABLE 14. OZONE HOURLY AVERAGE CONCENTRATIONS (ppb) AT WSU TRAILER SITE DURING THE PERIOD JULY 1-25, 1976.

TIME	DATE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0100	--	5	7	0	0	0	0	0	--	0	0	0	0	0	0	0
0200	--	9	6	0	--	0	0	0	--	0	0	0	0	0	0	0
0300	--	8	6	0	0	0	0	0	--	0	0	0	0	0	0	0
0400	1	5	5	0	0	0	0	0	--	0	0	0	0	0	0	0
0500	1	6	5	--	0	0	0	0	--	0	0	0	0	0	0	0
0600	4	1	4	0	0	0	0	0	--	0	0	0	0	0	0	0
0700	4	0	11	0	0	0	0	0	--	0	0	0	0	0	0	0
0800	5	1	16	1	0	0	31	0	--	0	0	11	0	0	0	0
0900	15	15	20	3	5	2	21	3	--	0	0	0	0	0	0	10
1000	21	22	21	5	--	8	18	16	--	0	0	8	5	0	0	10
1100	27	19	21	9	--	21	32	40	--	8	1	33	10	10	0	13
1200	38	20	24	12	--	39	34	76	--	3	5	68	25	10	5	20
1300	52	21	24	28	10	43	33	108	--	14	--	--	35	15	5	23
1400	49	31	26	31	11	37	44	150	--	12	--	81	30	35	5	11
1500	32	24	20	36	11	38	38	179	40	12	--	87	30	65	15	0
1600	28	19	12	36	13	23	48	136	18	11	--	76	15	80	15	0
1700	34	19	9	--	14	13	44	50	2	19	27	62	5	55	10	--
1800	21	17	5	17	--	10	30	25	0	17	25	41	3	40	5	--
1900	21	9	0	19	--	2	10	0	0	16	15	35	0	10	0	--
2000	22	4	0	9	5	0	5	--	0	7	5	25	0	0	0	--
2100	4	4	0	--	0	0	0	--	0	0	3	5	0	0	0	--
2200	0	4	0	4	0	0	0	--	0	0	0	0	0	0	0	--
2300	0	6	0	0	0	0	0	--	0	0	0	0	0	0	0	--
2400	0	4	0	0	0	0	0	--	0	0	0	0	0	0	0	--

(continued)

TABLE 14 (continued).

TIME	17	18	19	20	21	22	23	24	25
0100	--	3	0	0	8	0	0	0	5
0200	--	2	0	0	8	0	0	0	5
0300	--	2	0	0	0	0	0	0	3
0400	--	3	0	0	0	0	0	0	0
0500	--	0	0	0	0	0	0	0	0
0600	--	0	0	0	0	0	0	0	0
0700	--	1	1	0	0	0	0	0	0
0800	--	3	1	1	0	0	3	3	0
0900	--	7	4	8	2	5	5	8	5
1000	--	10	14	27	13	43	18	13	13
1100	--	18	22	--	58	25	28	65	20
1200	--	27	26	--	80	38	60	55	38
1300	--	43	30	--	80	50	65	73	45
1400	--	58	30	--	100	53	48	75	53
1500	--	41	27	62	43	68	25	78	102
1600	--	46	21	62	35	73	30	88	108
1700	--	54	16	58	40	53	--	83	140
1800	--	35	11	85	45	35	8	70	138
1900	--	15	11	48	28	30	15	50	103
2000	6	6	5	30	28	23	8	23	118
2100	2	1	2	20	13	13	0	8	95
2200	1	1	0	5	0	3	0	0	38
2300	0	1	0	5	0	0	0	0	23
2400	0	0	0	5	0	0	0	5	18

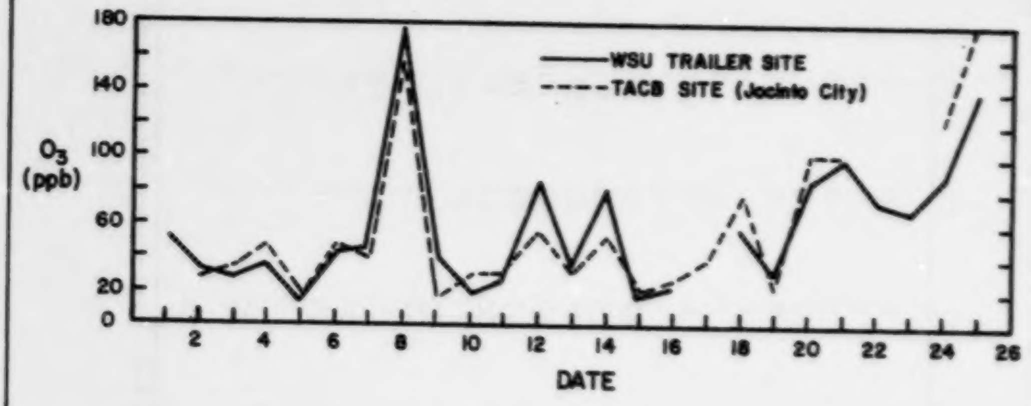

Figure 6. Peak hourly average ozone readings at two Houston area ground sites.

Hourly average ozone concentrations at the WSU trailer site in NW Houston equaled or exceeded the 80 ppb NAAQS on seven of the 25-day sampling period. Table 14 provides a summary of the hourly averages. As shown in Figure 6, the highest hourly value was 179 ppb recorded during the afternoon of July 8. In addition to July 8, the standard was equaled or exceeded on July 12, 14, 20, 21, 24 and 25. Figure 6 also contains a plot of ozone peaks recorded at the TACB site (Jacinto City) east of the downtown area. The curves for the two sites are very similar, with the exception that the WSU site generally showed a slightly higher peak on days when both stations exceeded 80 ppb. This is not unexpected, since with prevailing southeasterly winds the site in northwest Houston is farther downwind; and consequently, the air mass generally had more time to age.

The diurnal ozone pattern at the WSU trailer site was typical of that observed in other urban areas. Near zero ozone levels were recorded during nighttime and early morning hours, with peak values recorded during midday. Figure 7 shows the diurnal changes for the period July 7-12.

It was not uncommon for our airborne ozone monitor to record O_3 values in excess of 80 ppb on days when ground level stations were much below the standard. Figure 8 and 9 show two such examples. On July 5, the highest hourly average ozone value at the WSU trailer site was 14 ppb. In east Houston at the TACB site, the peak value was only 5 ppb higher. Ozone concentrations recorded aloft during the afternoon hours on July 5 are shown in Figure 8. It can be seen that O_3 in excess of 80 ppb existed in a small area about 15 miles to the west of Houston. A more dramatic example was observed on July 10 (Figure 9) when ground level ozone never exceeded 30 ppb, yet concentrations at $\sim$ 1500 ft., 20 miles to the southeast of Houston exceeded 130 ppb. There is little doubt that ozone concentrations in the region downwind of Houston generally exceed those monitored at ground stations in the Houston urban-industrial area.

It was stated earlier that oxidant episode conditions during July in the Houston area resulted from local emissions. This conclusion was based in part on aircraft survey flights, which always showed upwind ozone concentrations to be significantly below 80 ppb. The flights conducted on July 8th provide a good example. Winds were out of the east during the morning hours

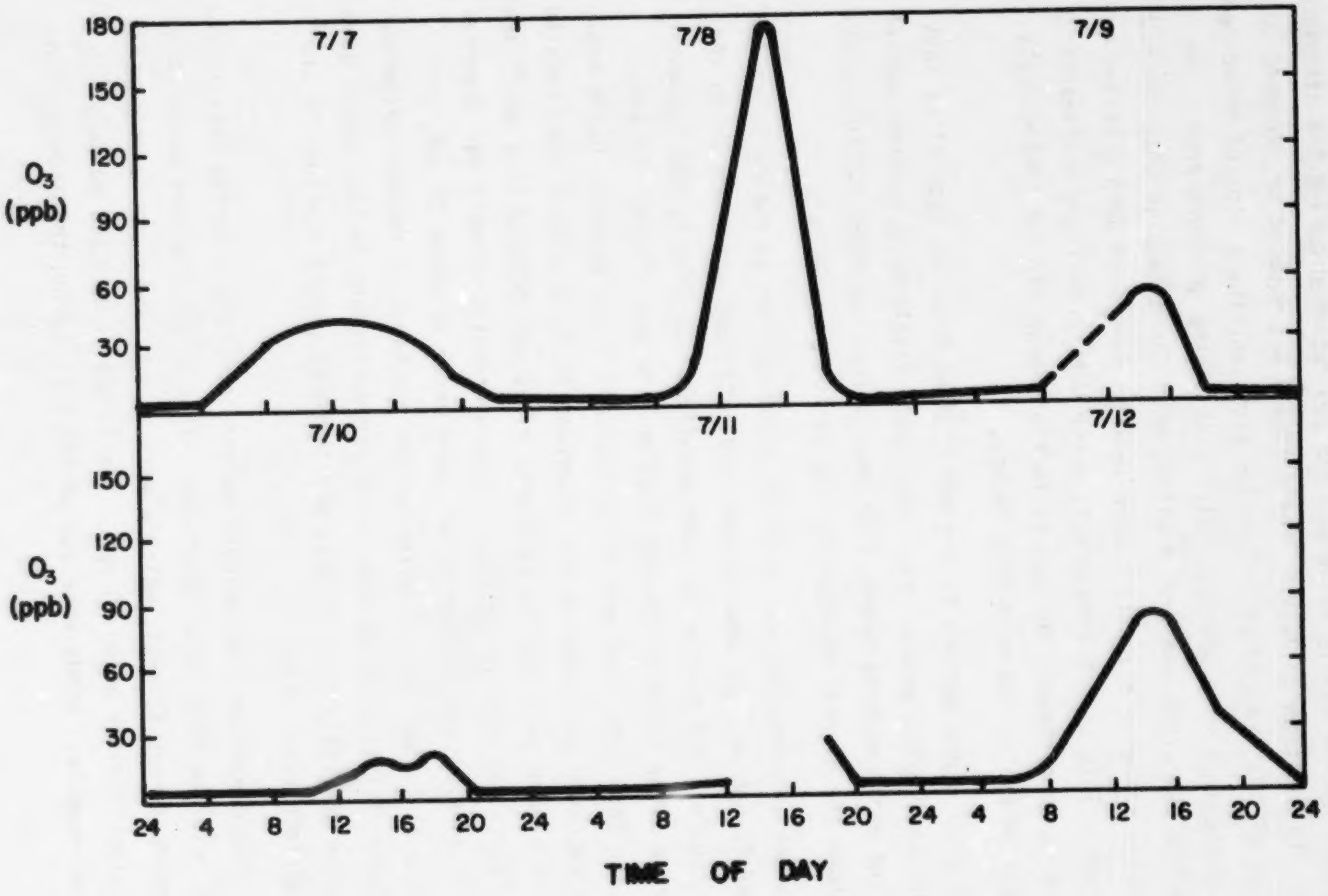

Figure 7. Dirurnal ozone pattern recorded between July 7 and 12, 1976.

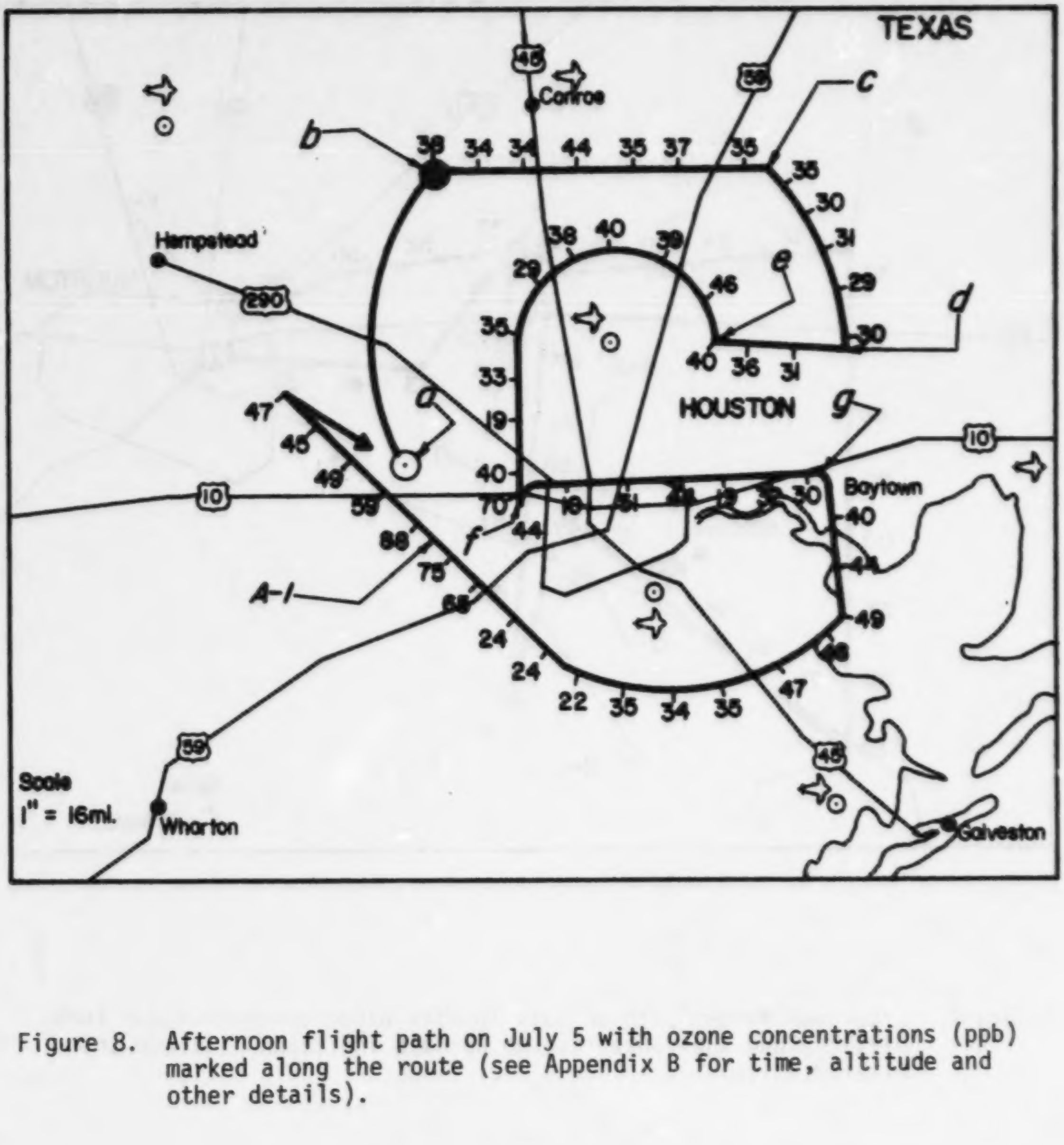
TEXAS
45
59
Conroe
c
b
38
34
34
44
35
37
35
35
30
31
29
30
d
Hempstead
290
38
40
39
29
46
e
35
40
36
31
33
HOUSTON
g
a
19
47
45
10
49
40
Baytown
10
59
70
18
51
30
40
88
f
44
75
A-1
68
49
24
24
22
35
34
35
47
59
45
Scale
1" = 16mi.
Wharton
Galveston

Figure 8. Afternoon flight path on July 5 with ozone concentrations (ppb) marked along the route (see Appendix B for time, altitude and other details).

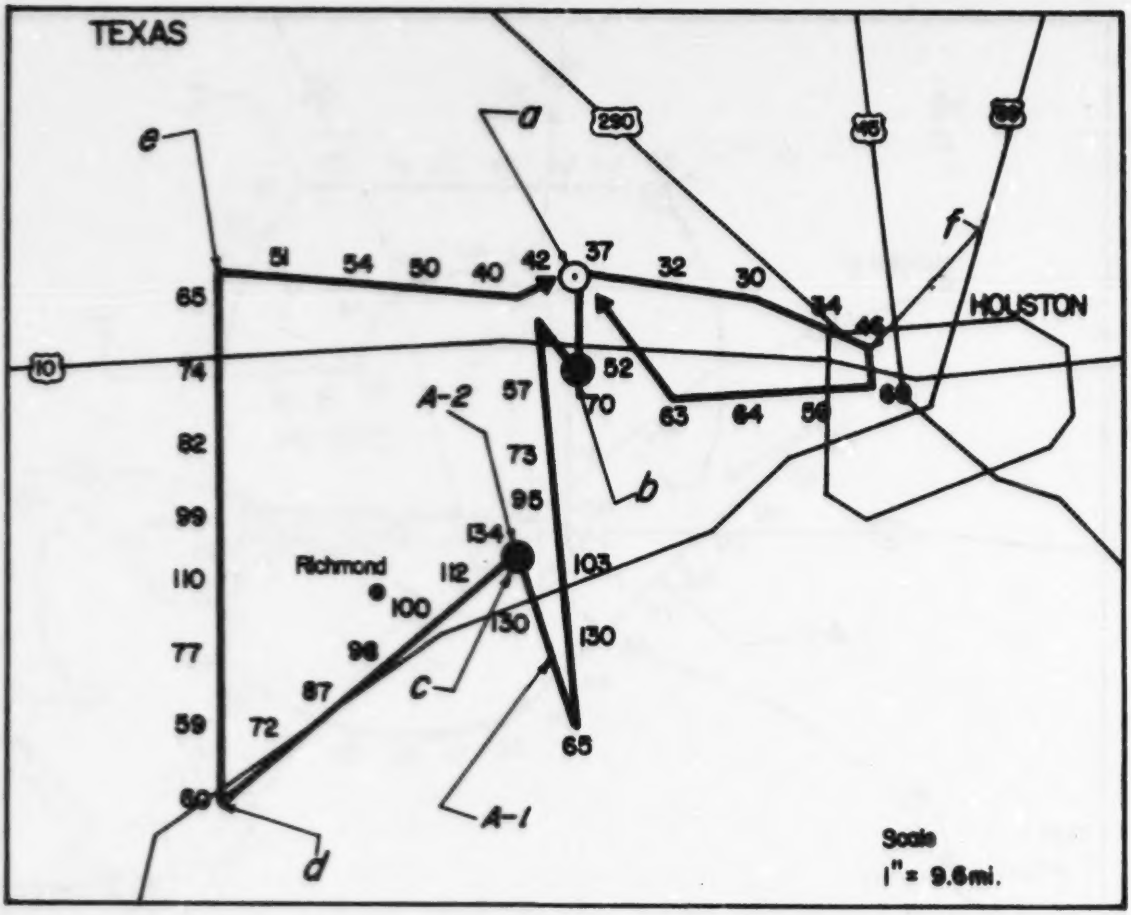
TEXAS
290
45
59
10
HOUSTON
Richmond
a
b
c
d
e
f
A-1
A-2
51
54
50
40
42
37
32
30
34
46
65
74
82
99
110
77
59
60
72
87
96
100
112
134
95
73
57
52
70
63
64
56
68
103
130
130
65
Scale
1" = 9.6mi.

Figure 9. Afternoon flight path on July 10 with ozone concentrations (ppb) marked along the route (see Appendix B for time, altitude and other details).

with a shift to southerly during the afternoon. As can be seen in Figure 10a, ozone concentrations throughout the Houston region were generally less than 40 ppb in the morning hours between 8 and 10 am. The upwind ozone concentration didn't increase much during the afternoon hours as shown in Figure 10b; however, in areas to the north and west of Houston, concentrations well in excess of 100 ppb were recorded. It should be recalled that a peak hourly average of 179 ppb was recorded at the WSU trailer site in northwest Houston on July 8.

During July, 1976, we observed no evidence of surface O_3 enhancement due to subsiding air masses from aloft. One or more vertical profiles were performed on each flight to check for this phenomenon. Figure 11a and b, which show ozone profiles recorded on July 8, are generally typical of the study period. The morning sounding shows a fairly constant 30 to 40 ppb ozone concentration from the surface to 8000'. It is clear from the afternoon profile that the high ozone band in the lower 3500' was generated at the surface and not the result of downward mixing from aloft. There was no significant change in O_3 concentration above 4000' through the day.

Ozone production resulting from photochemical processes involving only natural precursors has undergone intensive study recently. In a study conducted by Stanford Research Institute (14), strong evidence is presented to support the hypothesis that no local ozone synthesis occurs at rural locations. Ozone data from many rural monitoring stations were analyzed with the finding that at no season of the year did there exist a diurnal variation in ozone with an afternoon maximum similar to that observed in polluted atmospheres.

A similar conclusion was reached by Westberg (15) in a review prepared for the Environmental Protection Agency. In this study, the potential for ozone production in a rural air mass containing natural terpenic hydrocarbons was estimated based on reported hydrocarbon levels. Since the sum total of individual natural hydrocarbons seldom exceeds a few ppb, it is unlikely that a measurable quantity of ozone can be produced through the photooxidation of natural hydrocarbons in ambient air. We are aware of the reported high levels of "natural" hydrocarbons at a site north of Houston (16). This work

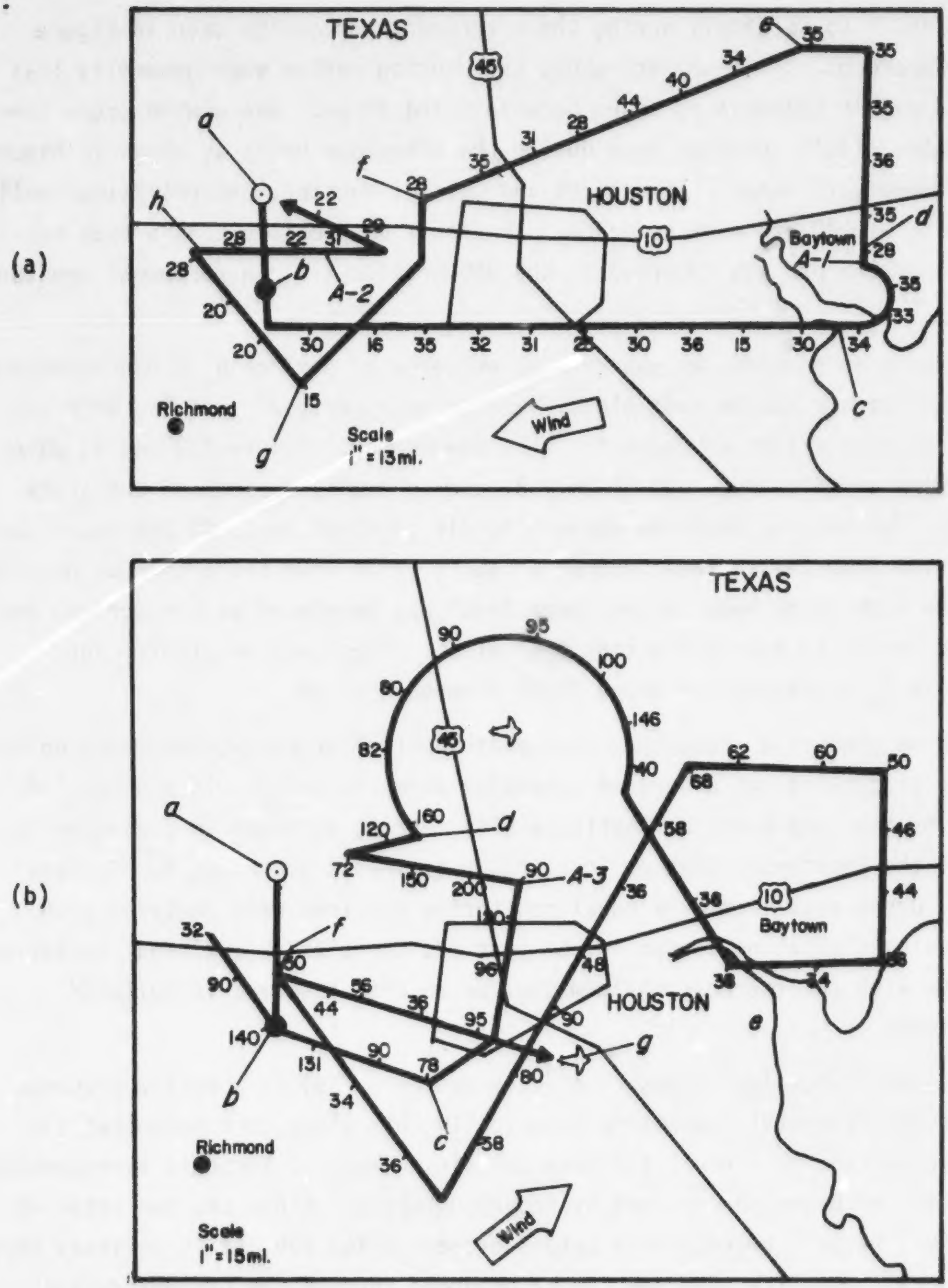
(a)
TEXAS
45
e
35
35
34
40
44
28
31
35
f
28
a
22
h
28
22
31
29
HOUSTON
10
35
36
35
d
Baytown
A-1
28
36
33
28
b
A-2
20
20
30
16
35
32
31
25
30
36
15
30
34
c
15
Richmond
g
Scale
1" = 13 mi.
Wind
(b)
TEXAS
90
95
100
80
146
45
82
40
62
60
50
68
120
160
d
58
46
a
72
150
200
90
A-3
36
38
44
10
Baytown
32
f
120
50
96
48
90
56
36
44
38
34
56
HOUSTON
140
95
90
e
131
90
78
80
g
b
34
c
58
Richmond
36
Scale
1" = 15 mi.
Wind

Figure 10. Morning (a) and afternoon (b) flight paths on July 8 with ozone concentrations (ppb) marked along the route (see Appendix B for time, altitude and other details.)

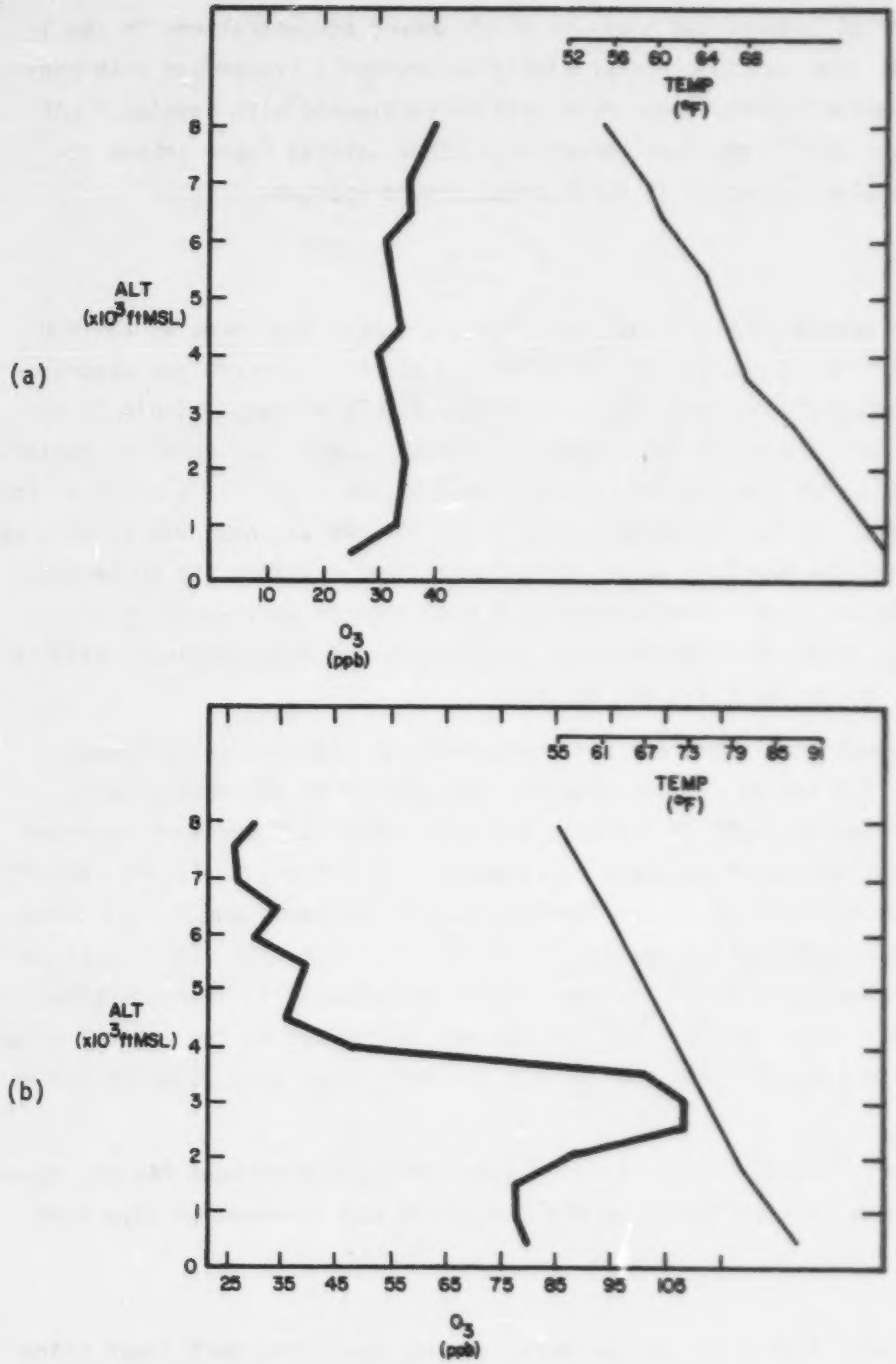

Figure 11. Morning (a) and afternoon (b) vertical soundings conducted on July 8, 1976 (see Appendix B for details).

involved a total hydrocarbon analysis which showed concentrations in the 1-10 ppm range. Due to the close proximity to Houston's tremendous anthropogenic hydrocarbon source, these data must be considered with caution.* At no time in our 1976 study were terpenic or other natural hydrocarbons observed in samples collected in rural areas around Houston.

PAN

Ambient peroxyacetyl nitrate concentrations were monitored at the WSU trailer site from July 2 to 23. An automated electron capture gas chromatograph was employed which provided a reading every 20 mintues. Table 15 summarizes the hourly average PAN concentrations throughout the sampling period. It can be seen that the presence of this oxidant was primarily limited to the daylight hours. On two occasions (July 4 and 23) PAN was observed to persist into the nighttime hours; however, on both of these evenings the concentrations were below 1 ppb. The absence of PAN during the early morning hours is noteworthy since this implies that a carry-over of photochemical oxidants from one day to the next did not occur.

The highest hourly average PAN measurement at the site in northwest Houston was 11.5 ppb on July 8; however, the average of all measurements between 10:00 AM and 4:00 PM was only 1.0 ppb. This is lower than recorded in other major metropolitan areas. Lonneman, Bufalini and Seila (17) reported an average of 18.4 ppb in Los Angeles, 6.3 in St. Louis and 3.7 in Hoboken, NJ, during the same daytime period. Without additional data, it is difficult to judge weather the 1.0 ppb average determined July, 1976, is representative of the Houston area. The overall average may be low due to the unusual meteorology during the July study period and the particular site at which PAN was monitored.

On a daily basis, there existed a good correlation between PAN and ozone. Figure 12 shows that little or no PAN production was observed on days when

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* During recent studies by EPA personnel at the same site, much lower hydrocarbon concentrations were recorded. The EPA study of January 4-6, 1978 found NMHC levels that varied between 200-500 ppb (18).

TABLE 15 . PAN HOURLY AVERAGE CONCENTRATIONS (PPB) AT WSU TRAILER SITE DURING THE PERIOD JULY 2-23, 1976.

	DATE											
TIME	2	3	4	5	6	7	8	9	10	11	12	13
0100	--	0	0	.1	0	0	0	0	0	0	--	0
0200	--	0	0	0	0	0	0	0	0	0	--	0
0300	--	0	0	0	0	0	0	0	0	0	--	0
0400	--	0	0	0	0	0	0	0	0	0	--	0
0500	--	0	0	0	0	0	0	0	0	0	--	0
0600	--	0	0	0	0	0	0	0	0	0	--	0
0700	--	0	0	0	0	0	0	0	0	0	--	0
0800	--	0	0	0	0	0	0	0	0	0	--	0
0900	0	0	0	0	0	0	0	0	0	0	--	0
1000	0	0	0	0	0	.3	0	0	0	0	--	0
1100	0	.2	0	0	.4	.6	1.8	.1	0	0	--	0
1200	0	.1	.1	.2	.3	1.0	3.5	.1	.2	0	5.1	.5
1300	--	.2	.2	.2	1.2	1.4	6.5	0	.4	.4	2.5	.9
1400	0	.2	.5	.3	.9	1.7	9.7	0	.6	1.5	4.0	.6
1500	0	.2	.5	0	1.3	1.7	11.5	0	.4	.9	4.8	.8
1600	0	0	.4	.1	.7	2.5	7.0	0	.4	.9	2.7	.6
1700	0	0	.3	.3	.5	2.0	2.6	.4	.8	.5	4.9	.3
1800	0	0	.2	.5	.8	2.3	2.2	.1	.9	.2	1.7	0
1900	0	0	.7	.6	.5	.2	1.1	0	.8	0	.6	0
2000	0	0	.7	.5	.4	0	0	0	.2	0	0	0
2100	0	0	.6	.5	0	0	0	0	0	0	.2	0
2200	0	0	.5	0	0	0	0	0	0	0	0	0
2300	0	0	.5	0	0	0	0	0	0	0	0	0
2400	0	0	.4	0	0	0	0	0	0	0	0	0

(continued)

TABLE 15 (continued).

TIME	14	15	16	17	18	19	20	21	22	23
0100	0	0	--	0	--	0	0	0	--	0
0200	0	0	--	0	--	0	0	0	--	0
0300	0	0	--	0	--	0	0	0	--	0
0400	0	0	--	0	--	0	0	0	--	0
0500	0	0	--	0	--	0	0	0	--	0
0600	0	0	--	0	--	0	0	0	--	0
0700	0	0	--	0	--	0	0	0	--	0
0800	0	0	--	0	--	0	0	0	--	0
0900	0	0	--	0	--	0	0	0	--	.1
1000	0	0	0	0	0	0	.5	1.1	--	.6
1100	0	0	.2	0	0	.2	.9	3.8	--	1.0
1200	.1	0	.3	.1	.3	.3	1.1	3.4	--	1.8
1300	.6	0	.6	.5	.9	.2	1.7	2.9	.6	2.8
1400	2.5	0	.3	.8	1.1	.3	1.2	4.0	1.3	1.6
1500	3.1	0	0	.8	.5	.2	1.0	.8	1.5	.5
1600	4.3	0	0	.8	.5	.2	1.0	.8	2.3	2.0
1700	.5	--	.2	.8	.5	0	1.0	1.0	1.6	1.3
1800	.3	--	0	.5	.5	0	.7	1.3	.7	1.6
1900	0	--	0	.2	.1	0	.6	.4	.6	2.8
2000	0	--	0	0	0	0	.3	0	.5	3.5
2100	0	--	0	--	0	0	0	0	0	1.6
2200	0	--	0	--	0	0	0	0	0	.6
2300	0	--	0	--	0	0	0	0	0	.1
2400	0	--	0	--	0		0	0	0	0

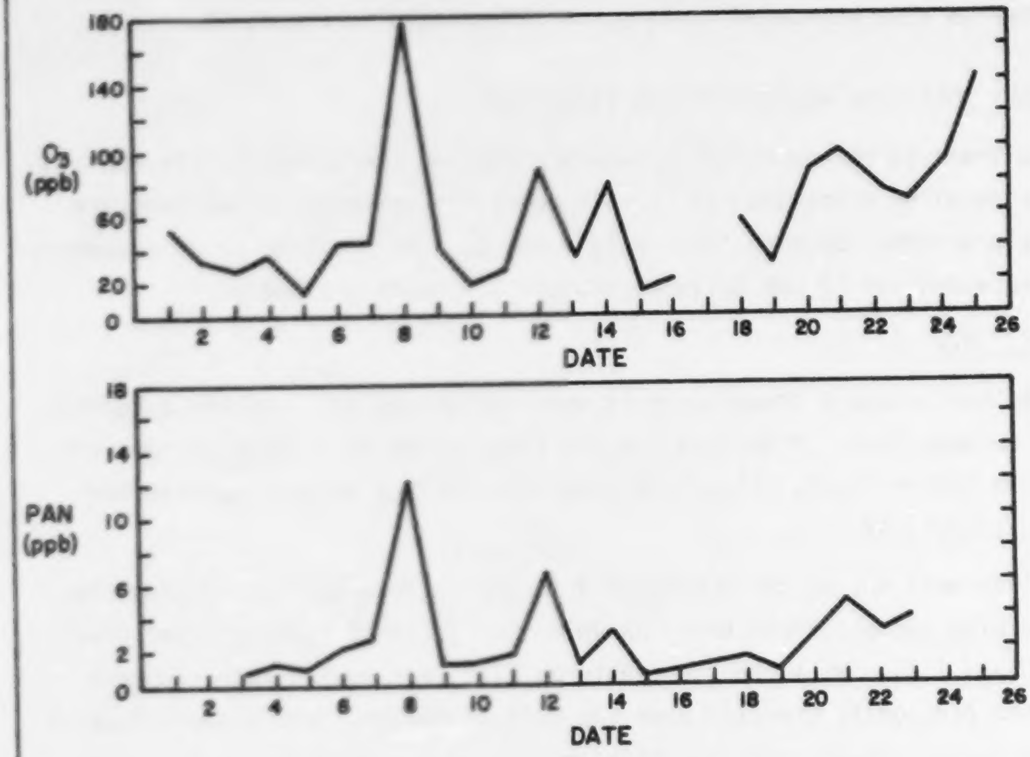


Figure 12. Relationship between peak hourly ozone and PAN concentrations in Houston during July, 1976.

ambient ozone levels remained below 80 ppb. However, on days when ozone showed high peak values, PAN concentrations peaked as well. Since PAN is considered to be a tracer of urban pollution, the perfect correlation between PAN and ozone episodes supports the earlier statement that high ozone levels observed in the Houston region during July, 1976, resulted from anthropogenic causes and not from stratospheric intrusion. The diurnal ozone and PAN patterns also coincided closely, as illustrated in Figure 13.

SECONDARY POLLUTANT PRODUCTION AND TRANSPORT

In order to characterize secondary pollutant production in the Houston area, a detailed discussion of the air chemistry observed on two separate days is provided. On both days, July 8 and 12, ground level ozone concentrations exceeded the 80 ppb National Ambient Air Quality Standard.

July 12, 1976

Weather patterns around July 12 were influenced by a western extension of the Bermuda High. High pressure and light winds were generally present up to the 500 mb level. Figure 14 shows the surface weather map for the morning of July 12.

Winds were out of the southeast from the surface to 5000' during the late morning and afternoon hours on July 12. Table 16 lists Houston winds at 1100 and 1715. With the southeasterly flow, air moving into southern Texas had previously traveled over the Gulf of Mexico. The onshore flow of warm, moist air caused numerous thunderstorms and a continual overcast in southeast Texas. Weather observers in the Houston area reported no less than 80% sky cover during the daylight hours of July 12. Maximum solar radiation measured at the WSU field laboratory on July 12 was approximately 60% of that recorded on a clear day.

Even though the skies were mostly overcast during the daylight hours on July 12, ozone levels in excess of 200 ppb were observed downwind of Houston in the afternoon hours. Ozone concentrations recorded during a morning flight in the Houston vicinity showed considerable variation in the zone from 1000 to 1500 ft above the surface. Some values exceeded 100 ppb, but in most areas the ambient ozone concentration was near or below 50 ppb. Most of the

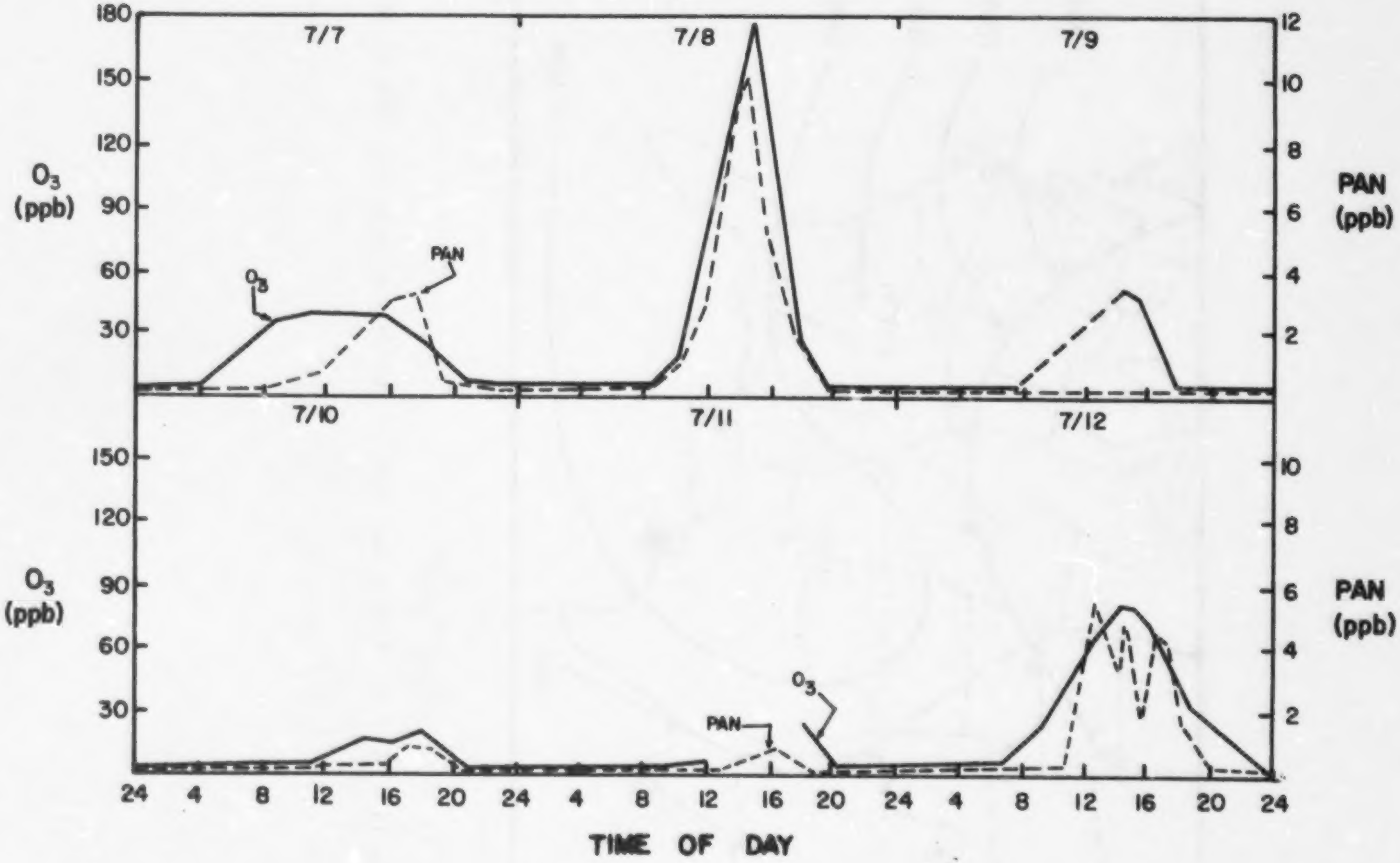


Figure 13. Diurnal ozone and PAN patterns in Houston during the period of July 7-12, 1976.

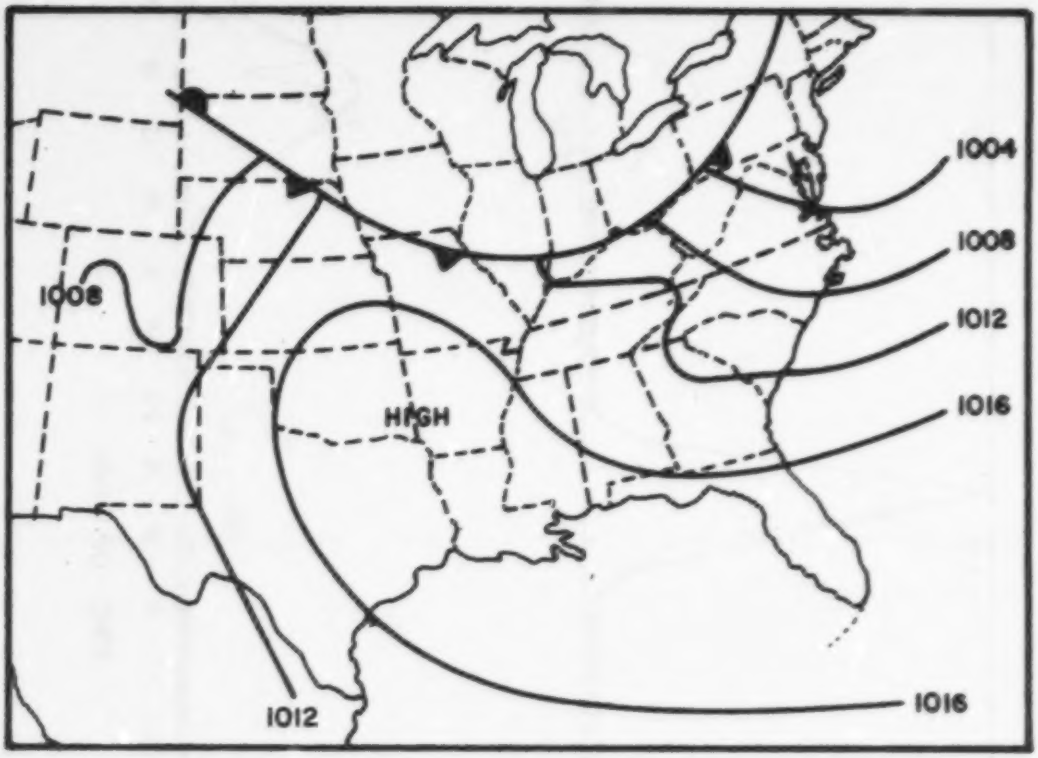

1004
1008
1012
1016
1008
HIGH
1012
1016

Figure 14. Surface weather map for the morning of July 12, 1976 (7 am EST).

higher readings were observed west of Houston while the upwind area to the east exhibited the lowest level.

TABLE 16. WINDS MEASURED AT THE WSU TRAILER SITE ON JULY 12, 1976.

HEIGHT (FEET)	1100		1715	
	D	S	D	S
SFC	140	12	170	9
700	100	5	122	10
1400	113	5	119	9
2000	119	9	122	8
2700	116	13	116	6
3300	106	16	120	7
3900	108	18	122	8
4500	107	17	120	9
5100	100	17	74	14

D = direction in degrees
S = speed in knots
SFC = surface

Figure 15 shows the morning flight path with ozone concentrations marked at specific points along the route. The flight began at point "a" at 0845. Following a spiral ascent and descent at point "b" the aircraft headed east at an altitude of approximately 1000 ft to a point "c" upwind of Baytown. Ozone concentrations all the way along this leg were below 45 ppb. It can be seen in Figure 15 that ozone concentrations along the upwind leg from point "c" to "d" were in the 30 - 40 ppb range. Ozone levels remained below 80 ppb along flight leg "e" - "f" as well as to the west of Houston along the most westerly portion of the route covered between points "f" and "g." As the aircraft approached the Houston downtown area enroute to spiral point "g", ozone concentrations increased dramatically with a high of 162 ppb recorded near the Astrodome. The ambient ozone levels remained above 80 ppb along

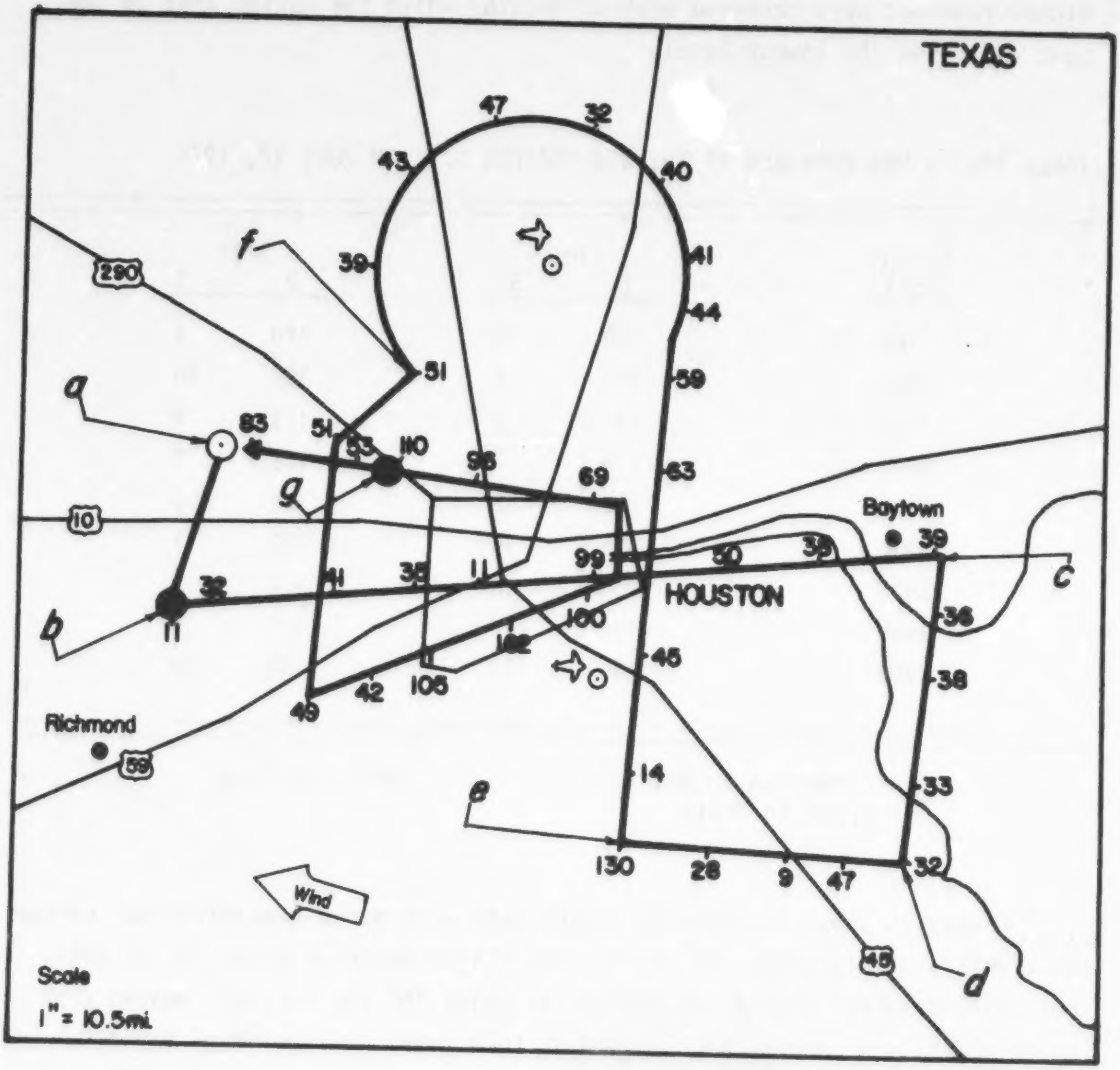

TEXAS
47
32
43
40
39
41
44
f
290
51
59
a
83
51
53
110
98
69
63
g
10
Baytown
39
99
50
38
c
32
41
35
11
HOUSTON
b
11
36
100
102
45
105
38
42
49
Richmond
59
14
33
e
130
28
9
47
32
Wind
45
d
Scale
1" = 10.5mi.

Figure 15. Morning flight path on July 12 with ozone concentrations (ppb) marked along the route (see text and Appendix B for time, altitude and other details).

most of the remainder of the route. The morning flight ended at Lakeside Airport, the point of departure, at 1130.

It is clear from the foregoing discussion that ozone levels well in excess of 100 ppb had developed at the 1000 to 1500 ft level to the west of Houston's industrial and downtown areas before noon on July 12. In contrast, air moving into this region from the east during this period contained 30-40 ppb ozone.

The two aircraft soundings at 0900 and 1100 were useful for establishing vertical pollutant profiles. Ozone and temperature changes with altitude at 0900 are shown in Figure 16. The ozone profile shows values in the 30 ppb range with little fluctuation between 500 and 9000 ft. The low ozone levels below 500 ft are probably the result of scavenging by nitric oxide. This hypothesis is supported by Figure 17 which shows that nitric oxide levels were highest below 500 ft. Based on this early morning vertical sounding there is no evidence of a significant carry over of ozone produced the day before. There does not appear to be any potential for increasing surface ozone levels by downward mixing of an ozone rich layer aloft.

By the time of the second spiral ($\sim$ 1100), ozone had developed rapidly through the lower 3000 ft. As shown in Figure 18, maximum concentrations were near 120 ppb at 2000 ft and about 160 ppb in a shallow layer at 2800 ft. The temperature profile was close to the dry adiabatic lapse rate throughout the 1000 to 4000 ft region and showed no inversion usually characteristic of the top of a surface mixing layer.

By 1500, ozone concentrations downwind of Houston had increased to greater than 150 ppb throughout the lower 2000 ft of the atmosphere. Figure 19 shows ozone and temperature profiles at a point approximately 20 miles northwest of Houston. It can be seen that the top of the ozone rich layer extended to at least 4000 ft. Above 4500 ft, ozone levels were in the 40 ppb range and therefore, had changed little since the morning measurement. A second vertical profile was flown during the afternoon flight at a point approximately 45 miles downwind of Houston. Ozone concentrations at this distance and time (1700) approached 200 ppb at the 2500 ft level and exceeded 100 ppb to over 4000 ft. Figure 20 graphically illustrates this ozone-altitude relationship. The change in temperature with altitude is also shown

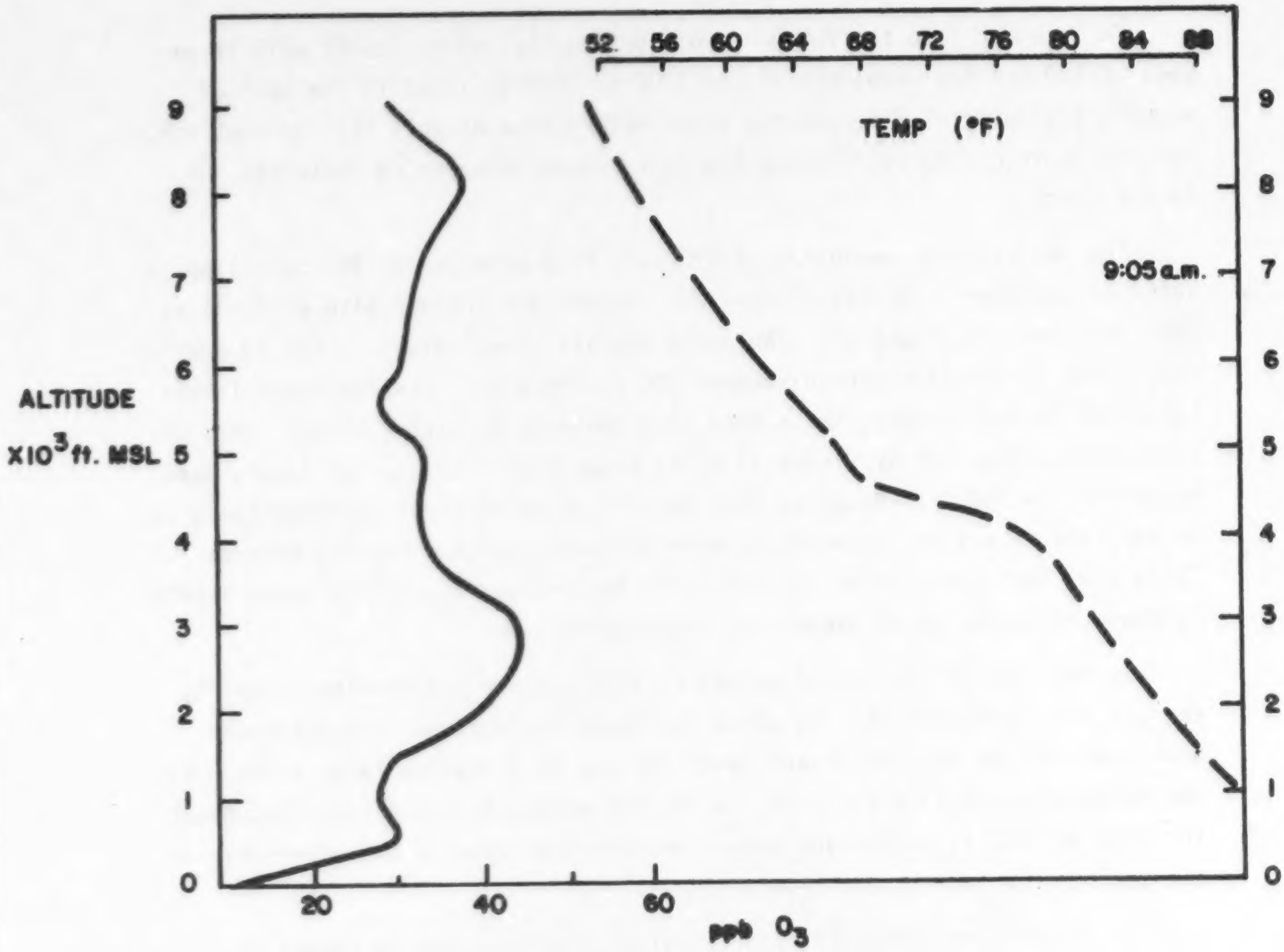


Figure 16. Ozone and temperature vertical profiles at about 9 am on July 12, 1976.

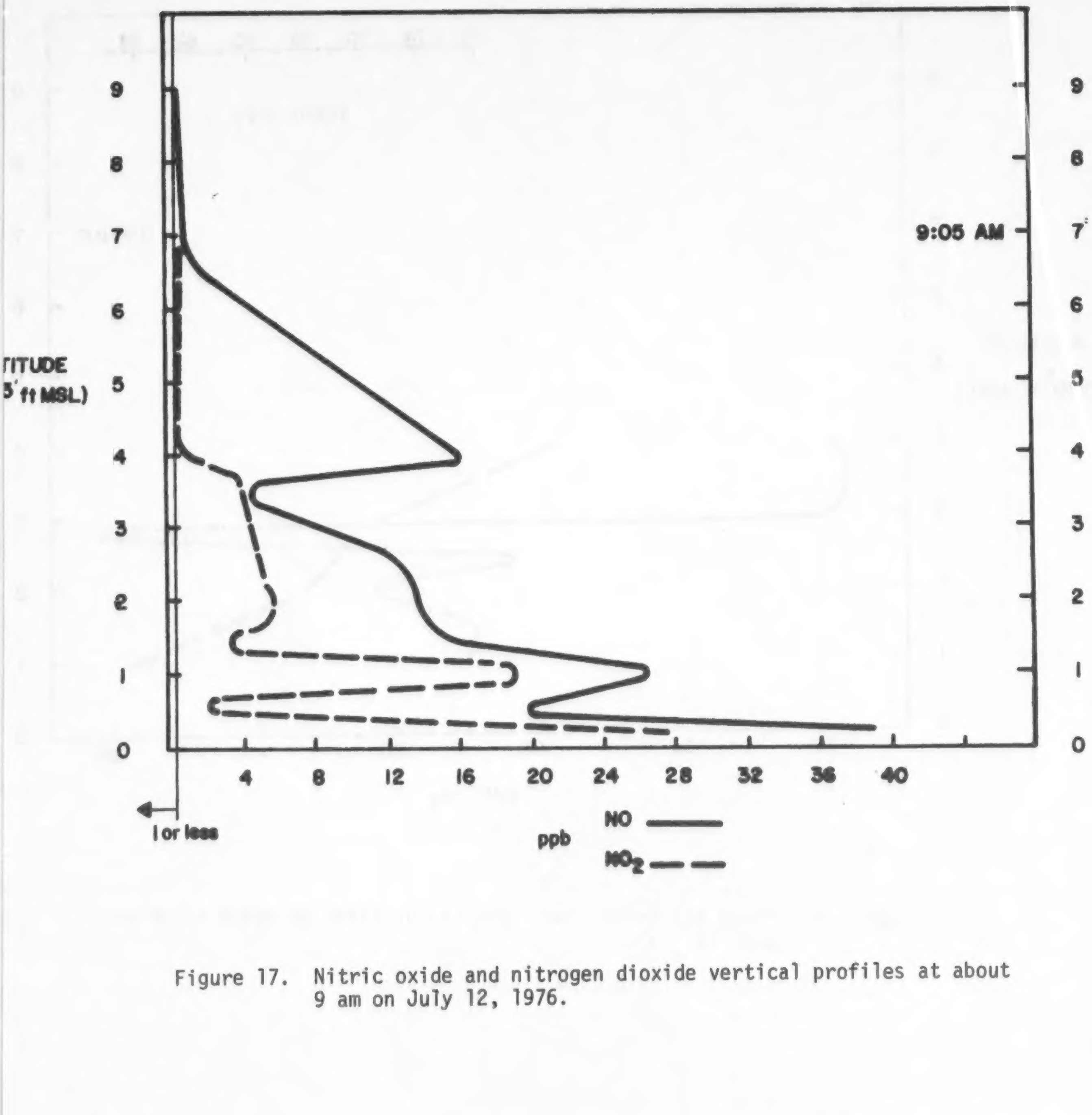


Figure 17. Nitric oxide and nitrogen dioxide vertical profiles at about 9 am on July 12, 1976.

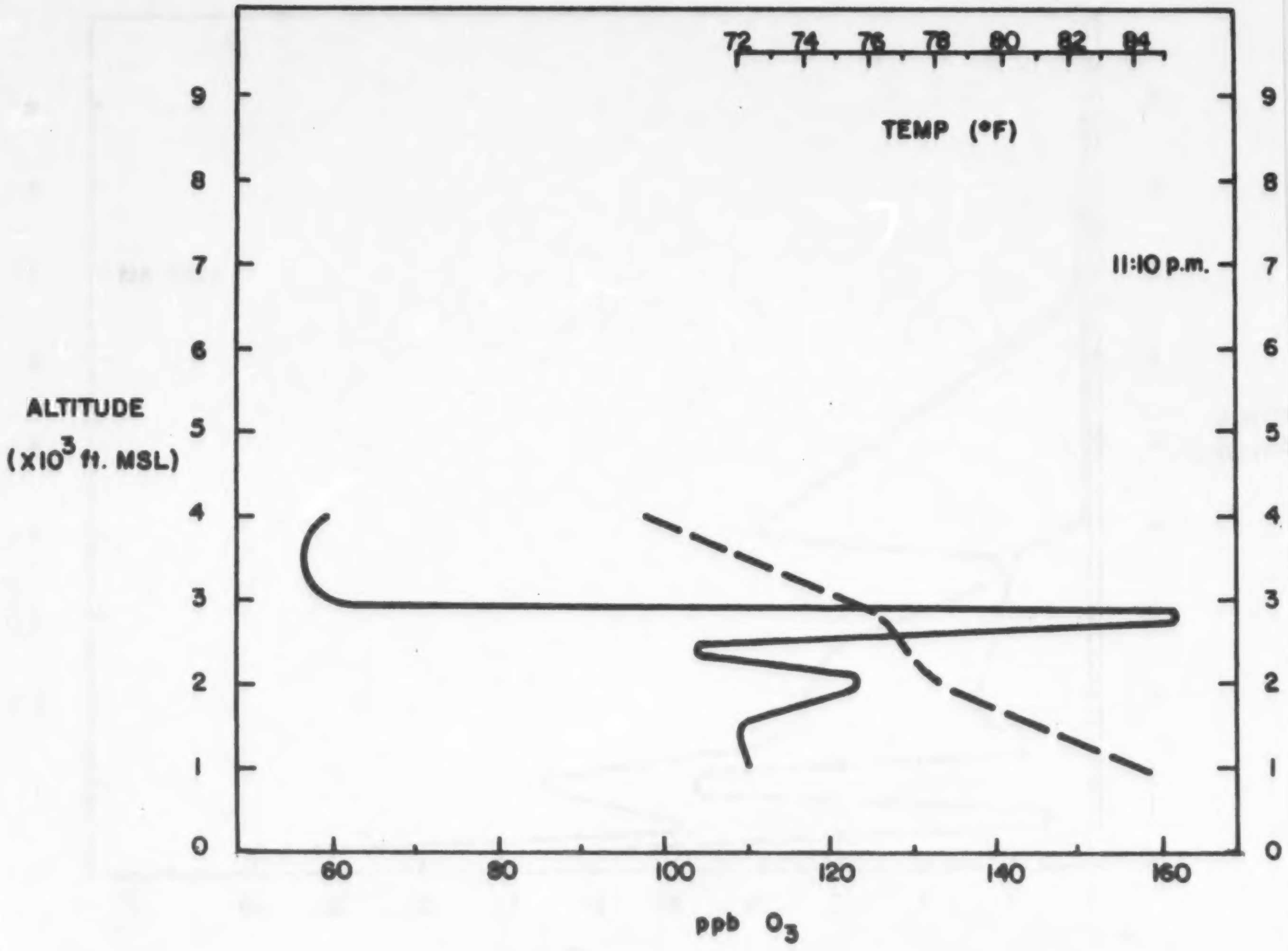


Figure 18. Ozone and temperature vertical profiles at about 11 am on July 12, 1976.

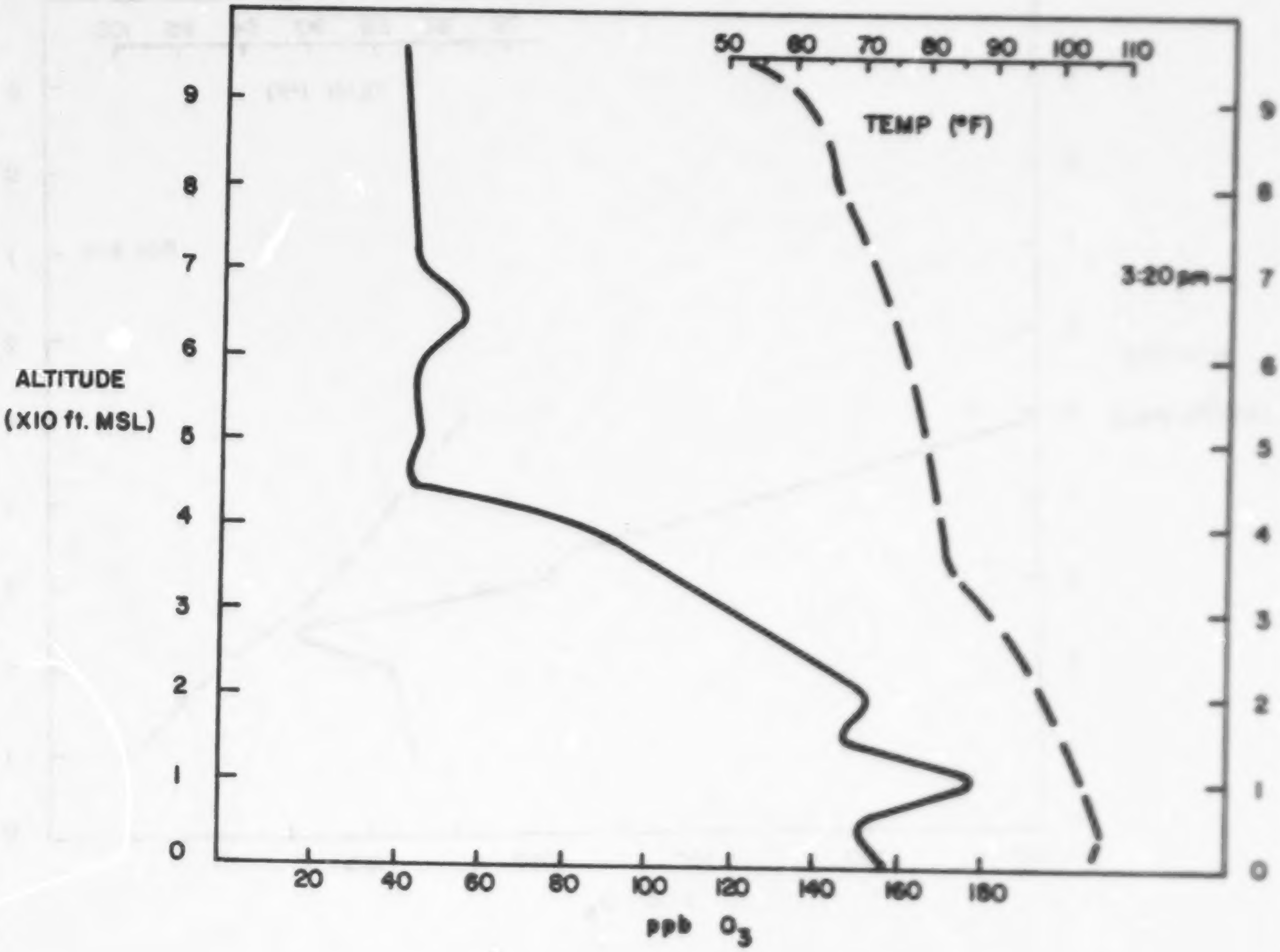


Figure 19. Ozone and temperature vertical profiles at about 3:15 pm on July 12, 1976.

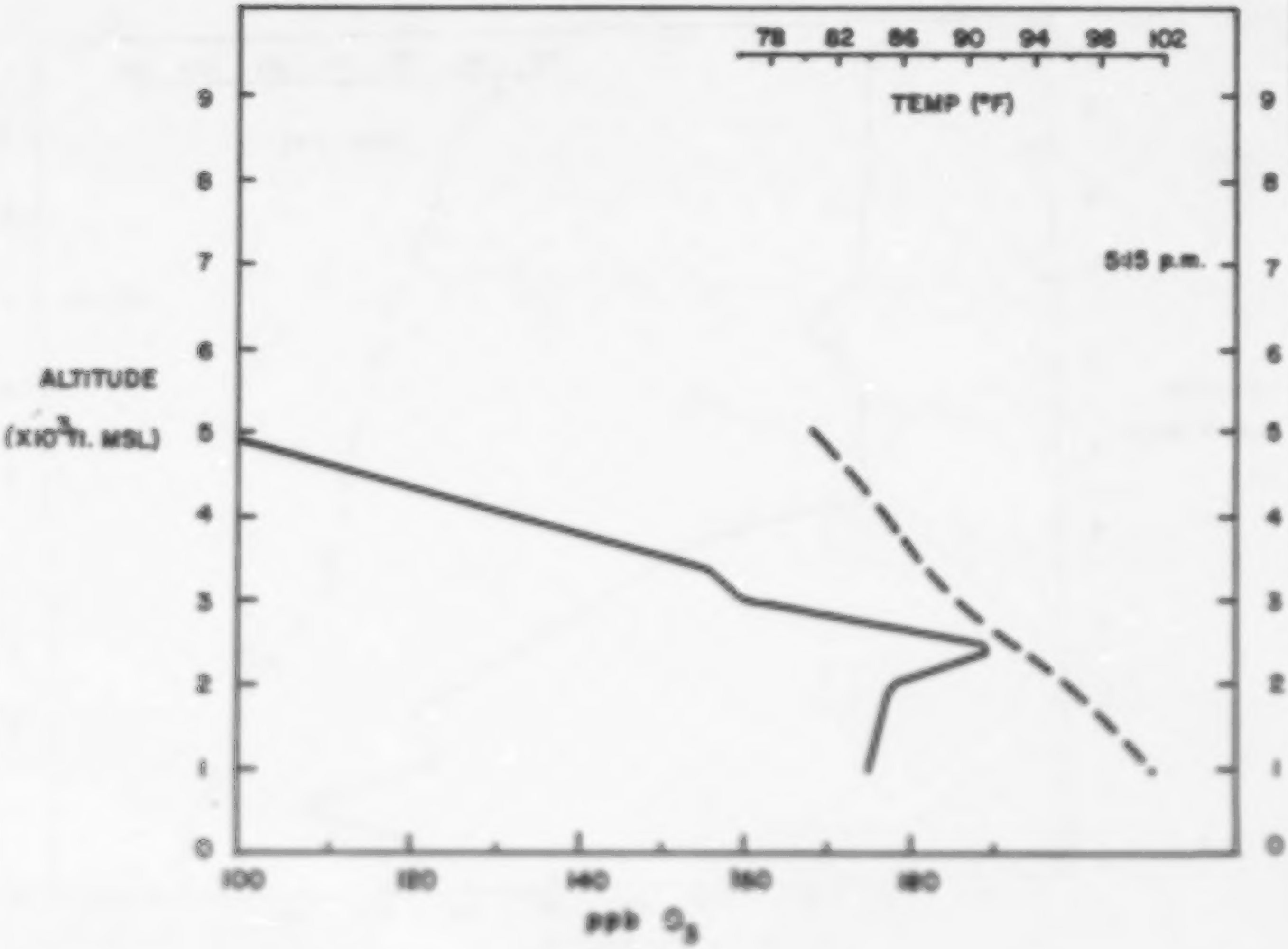


Figure 20. Ozone and temperature vertical profiles at about 5:15 pm on July 12, 1976.

in Figure 20. Once again, the lapse rate was near the dry adiabatic, and there was no indication of an inversion at the top of the mixing layer. Late in the afternoon the mixing layer in the area northwest of Houston was about 5000 ft deep.

Ozone concentrations recorded at surface stations around the Houston area on July 12 were much lower than the values observed aloft. Table 17 lists afternoon hourly averages at several different sites. Stations on the upwind side of Houston, such as Clute, didn't exceed 50 ppb. Monitoring sites closer in to the city exhibited maxima in the 60 to 70 ppb range; Fuqua = 60 ppb (south site in Figure 1), Clinton = 77 ppb (near TACB site in Figure 1), Aldine = 70 ppb (north site in Figure 1). The 87 ppb hourly average recorded between 1400 and 1500 at the WSU station in northwest Houston was the highest surface reading.

TABLE 17. SURFACE OZONE CONCENTRATIONS (ppb) ON JULY 12

TIME	CLUTE	CLINTON	FUQUA	ALDINE	WSU
1200	38	50	53	--	68
1300	41	60	61	56	--
1400	45	69	60	58	81
1500	44	77	53	70	87
1600	35	41	54	64	76
1700	34	43	53	60	62

Table 18 lists hourly average pollutant measurements at the Washington State University laboratory site on July 12. The diurnal ozone, NO_x, hydrocarbon and carbon monoxide patterns are typical of those observed in large urban areas. Ambient NO_x, hydrocarbon and carbon monoxide concentrations peaked during the 0600-0900 morning period. Ozone levels were low in the early morning hours. They began to increase about 1000 with a peak value of 87 ppb recorded during the early afternoon hours. A large increase in the NO_2/NO ratio accompanied the ozone change. The photochemical product

TABLE 18. SURFACE MEASUREMENTS AT WSU SITE ON JULY 12, 1976

TIME hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	PAN ppb
0100	0	16	17	.4	1.5	2.1	433	0
0200	0	9	16	.3	1.2	2.2	415	0
0300	0	4	16	.3	1.0	2.2	398	0
0400	0	24	14	.5	1.1	2.4	731	0
0500	0	25	14	.8	1.5	2.7	852	0
0600	0	48	14	.8	2.8	4.0	896	0
0700	0	113	22	1.5	4.7	3.5	2222	0
0800	0	106	25	1.7	5.0	3.6	1384	0
0900	0	61	31	1.1	3.1	2.9	1173	0
1000	8	31	49	.6	1.9	2.4	1290	0
1100	33	11	45	.7	1.7	2.2	504	0
1200	68	6	40	.8	1.4	2.0	817	5.5
1300	--	6	29	.7	1.4	2.1	298	2.3
1400	81	6	26	.8	1.1	2.0	275	3.6
1500	87	6	26	.6	1.2	2.0	--	4.6
1600	76	6	21	.3	1.1	1.9	357	1.8
1700	62	5	36	.5	1.3	1.9	314	4.4
1800	41	6	38	.5	1.1	1.9	308	2.0
1900	35	9	34	.4	1.5	1.9	271	1.0
2000	25	8	27	.5	2.0	1.9	269	.3
2100	9	9	35	1.0	1.6	1.8	383	0
2200	0	9	34	.6	1.7	2.1	440	0
2300	0	6	25	.6	1.3	2.0	313	0
2400	0	8	28	.6	1.3	2.1	425	0

PAN was present in measurable quantities during the period when ozone levels were elevated. Figure 21 summarizes these pollutant patterns on July 12.

The aerometric data shown in Figure 21 suggest a photochemical production mechanism for the afternoon ozone build-up. Nitric oxide, nitrogen dioxide and ozone concentrations throughout the afternoon hours are consistant with a photochemical stationary state condition.

Non-methane hydrocarbon/NO_x ratios during the 0600-0900 pollutant injection period varied between 11 and 13 at the WSU sampling site in northwest Houston (Table 18). This is not much different from the ratio observed in other major urban areas in the United States. Smog chamber experiments and field irradiations of captive air samples have shown that an initial Hc/NO_x ratio of 12-14 is near optimum for oxidant production (19). Afternoon oxidant levels in excess of 200 ppb downwind of Houston verify the high oxidant forming potential of emissions from the urban area.

Individual analysis of C_2-C_{10} hydrocarbons revealed a compositional breakdown of approximately 10% olefins, 25% aromatics and 65% paraffins in the 0600-0900 sample collected at the WSU laboratory. An aircraft sample collected at 1700 near Hempstead in a region of elevated ozone showed nearly the same percentage of olefins, aromatics and paraffins as recorded in the early morning sample. However, some of the more reactive olefins were absent in the afternoon sample. For example, i-butene, 1-butene, c-2-butene and t-2-butene, which totalled 25 $\mu g/m^3$ in the morning sample, were not present in the downwind high oxidant region. Also the propene/acetylene ratio had decreased from about .8 in the morning sample to .3 in the afternoon aircraft sample. The sum of the individual concentrations in this sample was approximately 200 $\mu g/m^3$ which is about five times the average background level (Table 10).

Data obtained during the afternoon flight on July 12 were very useful for defining the impact of Houston area emissions on the downwind region. Figure 22 shows the path flown and ozone concentrations at various points along the route. The flight began at Lakeside Airport and proceeded in a northwesterly direction to spiral point "b", approximately 20 miles downwind of Houston. Ozone levels between this spiral point and point "c", approximately 40 miles from Houston, seldom dropped below 100 ppb. A high reading

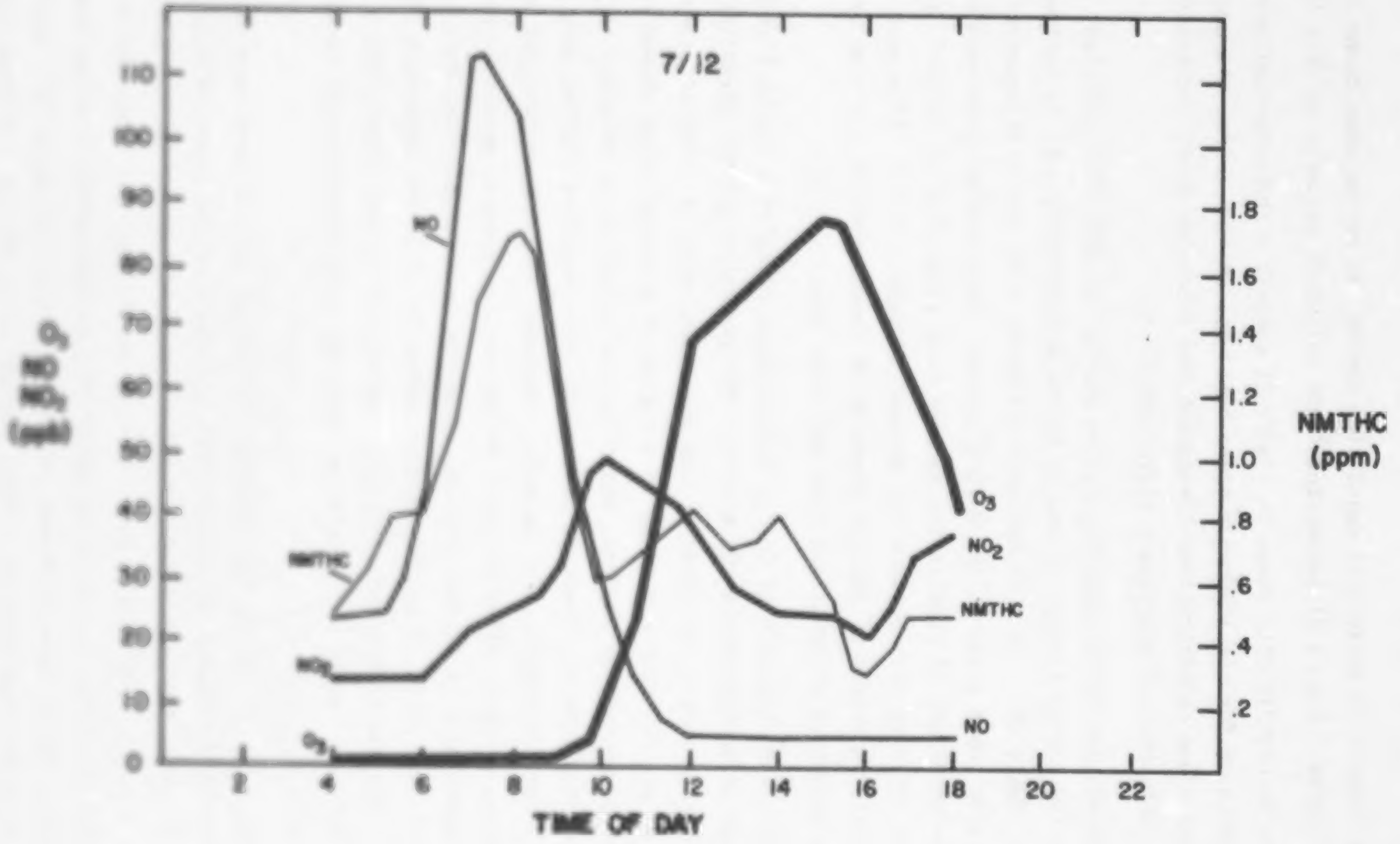


Figure 21. Pollutant changes at the WSU trailer site on July 12, 1976.

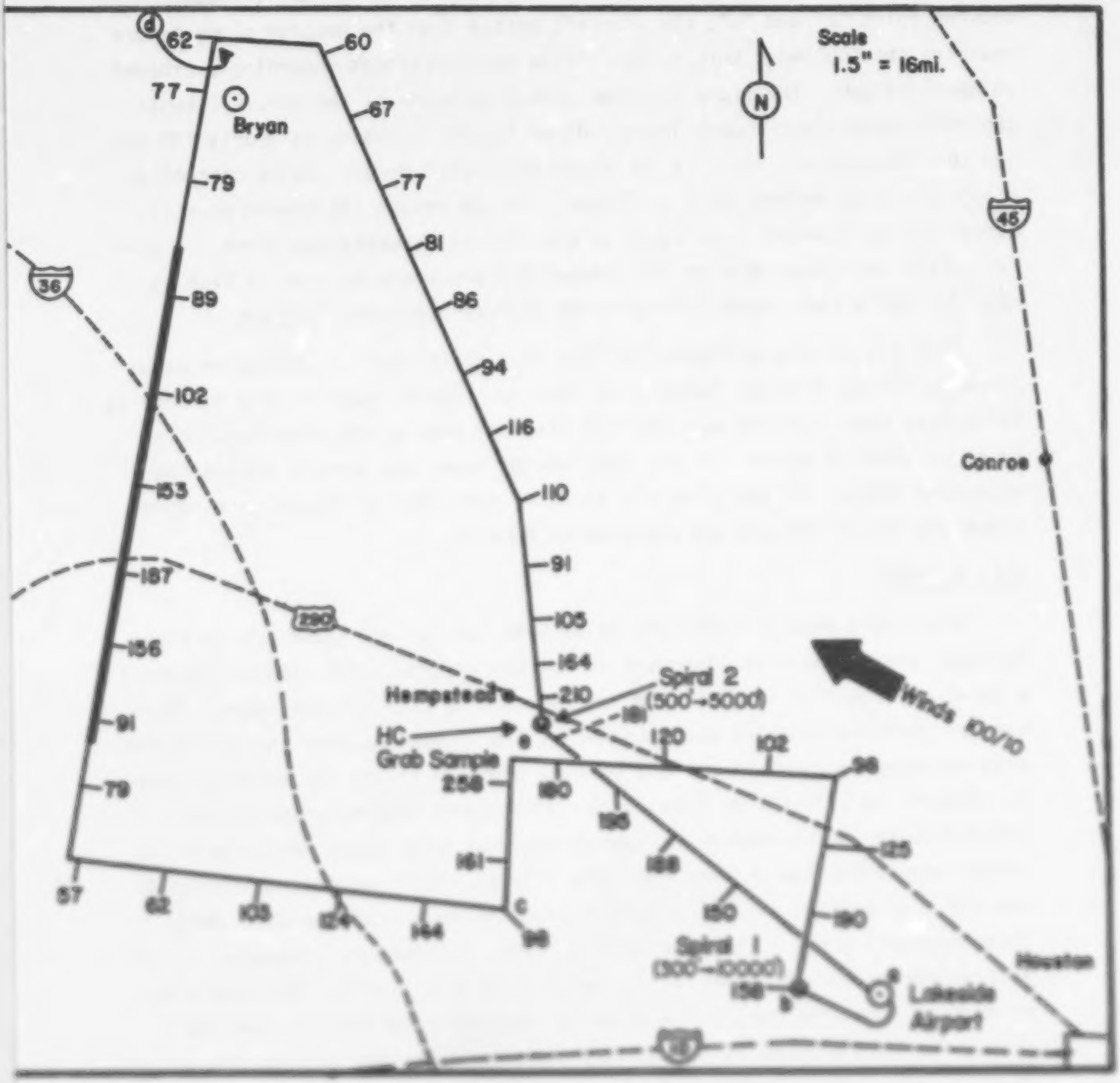

d
62
60
Scale
1.5" = 16mi.
N
77
Bryan
67
79
77
45
81
36
89
86
94
102
116
Conroe
153
110
91
187
290
105
156
164
Spiral 2
(500'→5000')
Hempstead
210
91
181
HC
Grab Sample
e
120
102
98
Winds 100/10
258
180
79
195
161
125
188
57
62
103
124
144
C
98
150
190
Spiral 1
(300'→10000')
Houston
158
b
a
Lakeside
Airport
10

Figure 22. Afternoon flight path on July 12 with ozone concentrations (ppb) marked along the route (see text and Appendix B for time, altitude and other details).

of 258 ppb was recorded south of Hempstead at about 1600. While traveling between point "c" and "d", the aircraft exited from the Houston plume before reaching the southwest turn point. Ozone concentrations accordingly dropped to about 60 ppb. The plume was then picked up again as the aircraft began the northbound track toward Bryan. Ozone levels increased to nearly 190 ppb and then dropped off again as the plane approached Bryan. Ozone concentrations around Bryan were down to 60 ppb. On the return leg toward Houston, ozone levels increased once again as the aircraft entered the plume. A spiral ascent near Hempstead at 1715 showed 100 ppb ozone existed as high as 5000 ft, while some readings nearer the surface approached 200 ppb.

This flight data collected on July 12 clearly shows a pronounced ozone plume as far as 90 miles downwind of Houston. Ozone readings were as high as 180 ppb at that distance and remained elevated over a cross-sectional distance of about 45 miles. A very deep mixing layer was present during the afternoon hours. At approximately 45 miles northwest of Houston, an ozone concentration of 100 ppb was recorded at 5000 ft.

July 8, 1976

Skies were mostly cloud covered between sunrise and sunset on July 8. National Weather Service observers at Houston International Airport reported a total sky cover of 10 tenths or overcast during the daylight hours. Percent of possible sunshine was recorded as 34%. Thunderstorms in the Houston area resulted in rainfall amounts varying from .46 in. at the Intercontinental Airport to 1.38 in. at Hobby. In spite of the seemingly unfavorable conditions for photochemical oxidant production, high ozone levels were recorded around Houston on this day. The 179 ppb hourly average monitored at the WSU trailer site was the highest during the July study period. Very light easterly winds during the morning hours, followed by a reversal in direction during the afternoon hours, appears to have limited the dispersion of Houston area emissions. Consequently, secondary pollutants produced from precursors emitted in the morning remained along the western fringes of Houston rather than being transported long distances downwind, as was the case on July 12.

Table 19 lists surface winds at Houston's two major airports. It can be seen that winds were light and somewhat variable during the morning hours but primarily from the northeasterly quadrant. About mid-afternoon the winds showed a significant increase in velocity with an accompanying shift to southwest.

TABLE 19. SURFACE WINDS RECORDED AT HOUSTON AREA AIRPORTS ON JULY 8, 1976

TIME (CDT)	Hobby Direction	Hobby Speed(kts)	Intercontinental Direction	Intercontinental Speed(kts)
0700	000	0	350	4
0800	030	5	020	4
0900	050	6	050	6
1000	050	4	110	4
1100	090	2	000	0
1200	200	3	310	2
1300	230	4	280	3
1400	080	4	050	4
1500	080	5	020	4
1600	180	15	010	3
1700	200	4	200	11
1800	220	6	250	9
1900	190	5	190	7

Figure 23 shows that during the late afternoon hours, high ozone levels covered a region approximately 20 miles wide and at least 40 miles long north and west of Houston. The limited dispersion accompanied by significant oxidant production makes July 8 an interesting day in which to examine chemical changes in the Houston atmosphere. As pointed out in an earlier section, air quality data collected on July 8 suggest anthropogenic precursors emitted in the Houston urban-industrial complex as the sole source of the elevated oxidant levels. There was no evidence for ozone enhancement due to long range transport or natural mechanisms on this day.

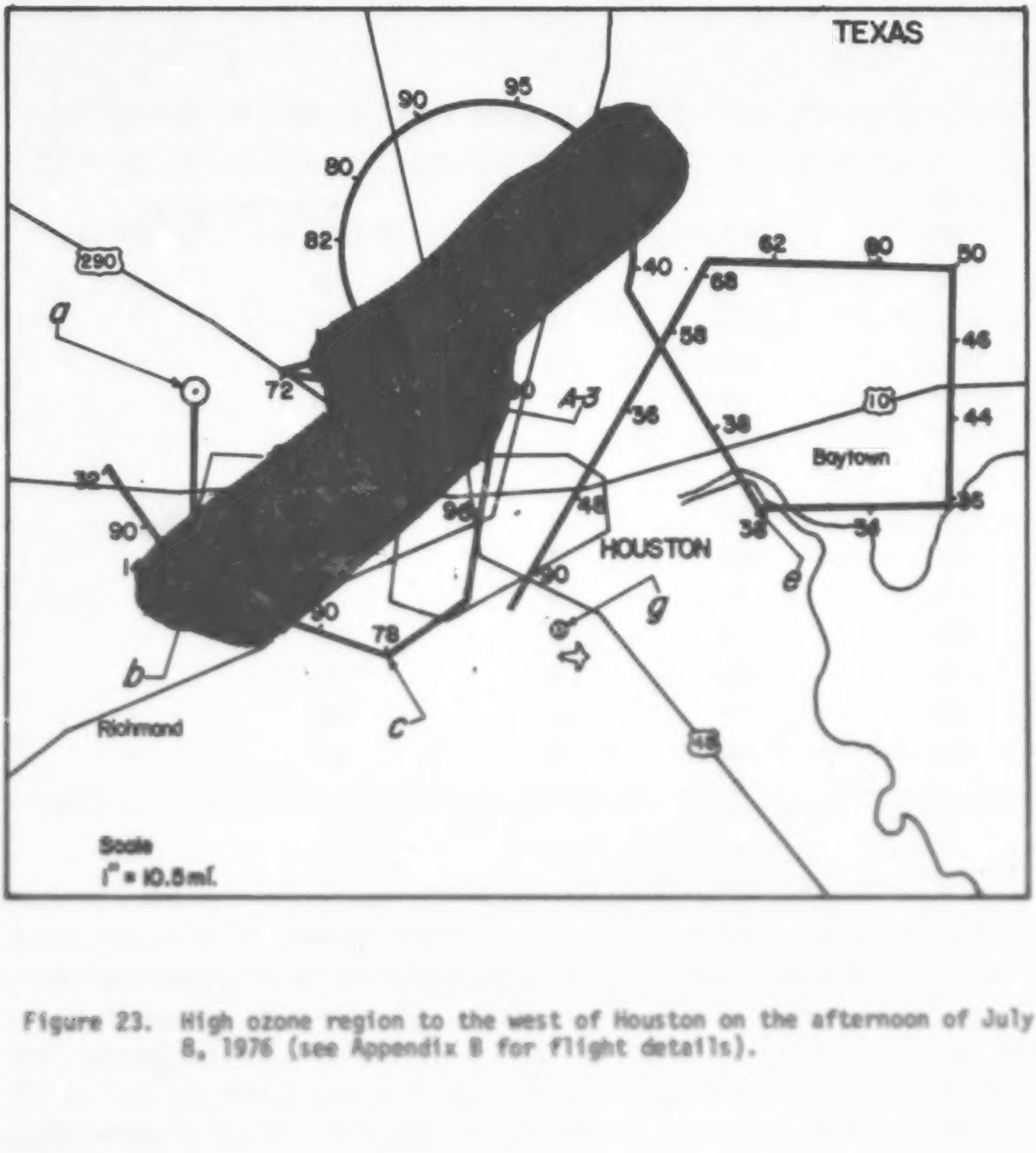

TEXAS
90
95
80
82
290
a
72
A-3
40
62
60
50
68
58
46
36
38
10
44
Baytown
32
90
96
48
HOUSTON
38
34
36
e
50
g
90
78
b
c
Richmond
45
Scale
1" = 10.5 mi.

Figure 23. High ozone region to the west of Houston on the afternoon of July 8, 1976 (see Appendix B for flight details).

Figure 24 shows the diurnal behavior pattern of various ambient pollutants on July 8. The data used to construct this diagram were gathered at the WSU trailer site in northwest Houston. All of the diurnal pollutant changes shown in Figure 24 are consistent with a photochemical oxidant producing mechanism. Following the NO-NO_2 cross-over time (∿ 9 am), ozone levels developed rapidly, reaching a peak hourly average at 3 pm CDT and then dropping off to less than 50 ppb by 5 pm. PAN production correlated closely with ozone formation after an initial lag of about one hour. Non-methane hydrocarbon and nitric oxide concentrations decreased throughout the morning hours. The morning Hc/NO_x ratio was about 8 at the ground level monitoring site. This is in the range favorable for oxidant production.

The one inconsistency in the ground data is the O_3-NO_2/NO relationship during the afternoon hours when ozone concentrations were at their maximum. The NO_2/NO ratio was about 6, which is at least a factor of 2 below what it should be based on photochemical stationary state conditions. This is one feature that we observed quite often in air masses that contained ozone levels greater than 100 ppb. We suspect that our nitrogen oxide monitors possess insufficient accuracy when NO levels are less than 5 ppb. For example, afternoon NO_2 levels on July 8 varied between 20 and 26 ppb, while concurrent NO concentrations averaged 4 ppb. If the NO concentration was actually 2 ppb or less, the NO_2/NO ratio would have been compatible with the 150 to 180 ppb ambient ozone concentration.

Individual hydrocarbon concentrations measured at various times and locations on July 8 are summarized in Tables 20, 21, 22 and 23. The two aircraft samples collected during the morning hours (Tables 20 and 21) are consistent with an east to west air movement during the morning hours. The 53.5 $\mu g/m^3$ of hydrocarbons in sample A-1 collected east of Baytown at about 9:15 is in the range normally representative of background air. Carbon monoxide, fluorocarbon-11 and carbon tetrachloride concentrations were also typical of those encountered in background air. By contrast, the sample collected to the west of Houston (A-2, Table 21) contained a total of 404 $\mu g/m^3$ of hydrocarbons. The anthropogenic tracers, carbon monoxide, F-11 and CCl_4 were 3 to 6 times more concentrated in this sample.

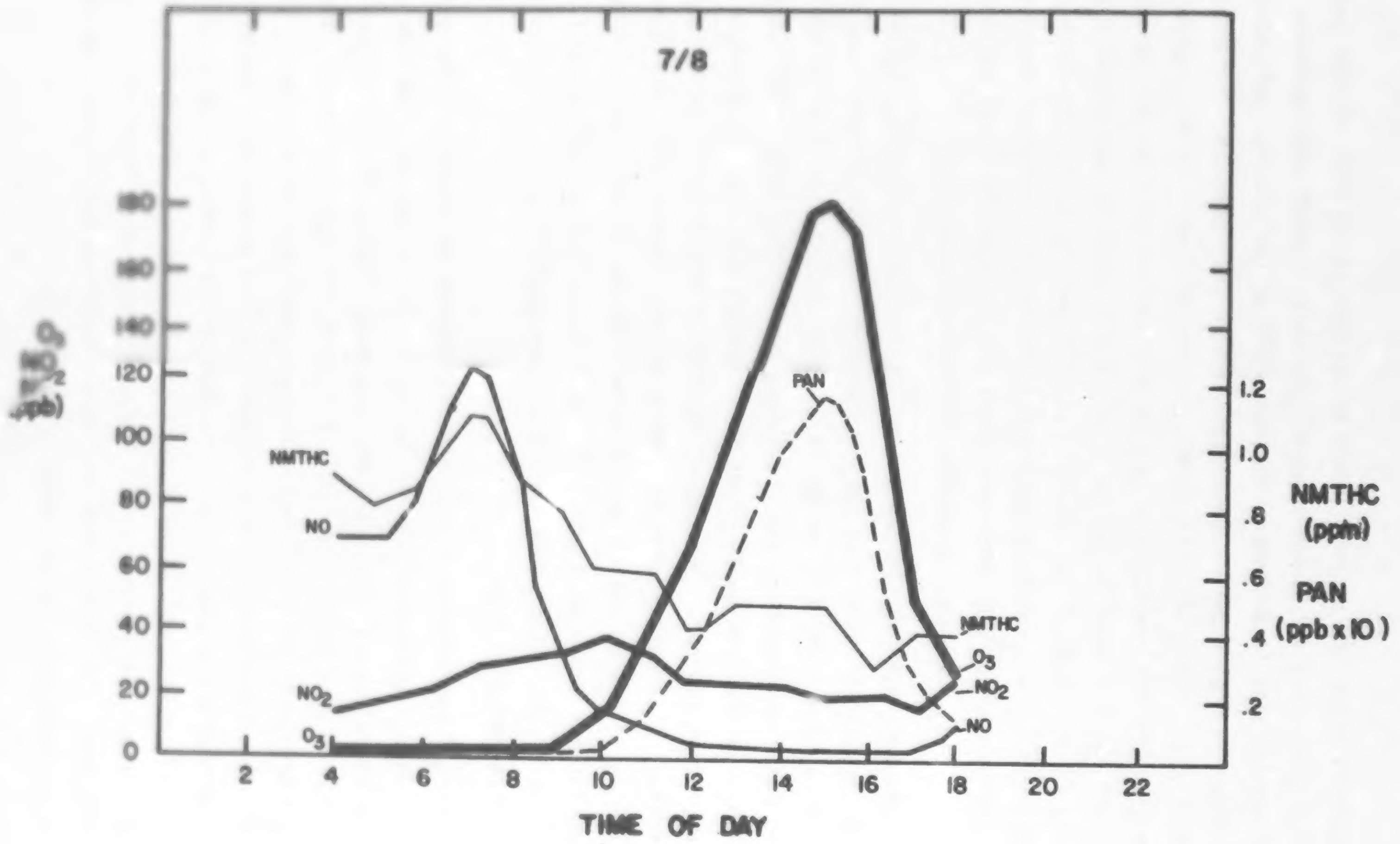


Figure 24. Pollutant changes at the WSU trailer site on July 8, 1976.

TABLE 20. HYDROCARBON, HALOCARBON AND CO LEVELS IN SAMPLE A-1 COLLECTED E. OF BAYTOWN (3000') AT 9:15 AM ON JULY 8, 1976.

µg/m³	Hydrocarbon	µg/m³	Hydrocarbon
2.5	Ethane	1.5	2,3-Dimethylpentane
1.0	Ethylene	2.5	3-Methylhexane
4.0	Acetylene	--	2,2,3-Trimethylpentane
1.0	Propane	--	n-Heptane
--	Propene	--	Methylcyclohexane
2.0	i-Butane	--	2,4-Dimethylhexane
2.0	n-Butane	--	2,3,4-Trimethylpentane
--	1-Butene	9.0	Toluene
1.0	i-Butene	--	2,3-Dimethylhexane
--	t-2-Butene	2.0	2-Methylheptane
--	c-2-Butene	2.0	3-Ethylhexane
1.5	i-Pentane	--	n-Octane
1.0	n-Pentane	2.5	Ethylcyclohexane
--	1-Pentene	1.0	Ethylbenzene
--	t-2-Pentene	1.5	p & m-Xylene
--	c-2-Pentene	--	Styrene
--	Cyclopentene	--	o-Xylene
1.0	Cyclopentane	--	n-Nonane
--	2,3-Dimethylbutane	1.0	i-Propylbenzene
1.0	2-Methylpentane	.5	n-Propylbenzene
1.5	c-4-Methyl-2-Pentene	1.0	p-Ethyltoluene
1.0	3-Methylpentane	--	m-Ethyltoluene
1.0	1-Hexene	1.0	o-Ethyltoluene
1.0	n-Hexane	1.0	1,3,5-Trimethylbenzene
--	t-2-Hexene	1.0	1,2,4-Trimethylbenzene
--	c-2-Hexene	--	1,2,3-Trimethylbenzene
--	Methylcyclopentane	1.0	Methylstyrene
--	2,4-Dimethylpentane	1.0	1,3-Diethylbenzene
5.0	Benzene	--	1,4-Diethylbenzene
.5	Cyclohexane		

Total Individual Hydrocarbons	µg/m³	%		
Σ Olefin	4.5	8	CH_4(ppm)	2.0
Σ Aromatic	24	45	CO(ppm)	.5
Σ Paraffin	25	47	$CFCl_3$(ppt)	149
TOTAL	53.5		CCl_4(ppt)	198

-- Less than .5µg/m³

TABLE 21. HYDROCARBON, HALOCARBON AND CO LEVELS IN SAMPLE A-2 COLLECTED W. OF HOUSTON (1000') AT 10:10 AM ON JULY 8, 1976.

$\mu g/m^3$	Hydrocarbon	$\mu g/m^3$	Hydrocarbon
14.5	Ethane	8.0	2,3-Dimethylpentane
19.5	Ethylene	10.0	3-Methylhexane
8.5	Acetylene	5.0	2,2,3-Trimethylpentane
26.0	Propane	3.5	n-Heptane
14.0	Propene	--	Methylcyclohexane
34.5	i-Butane	1.5	2,4-Dimethylhexane
31.0	n-Butane	1.0	2,3,4-Trimethylpentane
3.5	1-Butene	27.0	Toluene
3.5	i-Butene	1.0	2,3-Dimethylhexane
--	t-2-Butene	3.5	2-Methylheptane
--	c-2-Butene	2.0	3-Ethylhexane
35.0	i-Pentane	2.5	n-Octane
18.0	n-Pentane	1.0	Ethylcyclohexane
5.5	1-Pentene	4.5	Ethylbenzene
1.5	t-2-Pentene	13.0	p & m-Xylene
3.0	c-2-Pentene	2.0	Styrene
3.5	Cyclopentene	6.0	o-Xylene
2.5	Cyclopentane	2.0	n-Nonane
2.5	2,3-Dimethylbutane	1.5	i-Propylbenzene
10.5	2-Methylpentane	1.5	n-Propylbenzene
2.5	c-4-Methyl-2-Pentene	4.5	p-Ethyltoluene
11.5	3-Methylpentane	--	m-Ethyltoluene
2.5	1-Hexene	2.0	o-Ethyltoluene
11.0	n-Hexane	3.0	1,3,5-Trimethylbenzene
1.0	t-2-Hexene	5.5	1,2,4-Trimethylbenzene
--	c-2-Hexene	2.0	1,2,3-Trimethylbenzene
5.5	Methylcyclopentane	.5	Methylstyrene
2.0	2,4-Dimethylpentane	1.5	1,3-Diethylbenzene
13.5	Benzene	1.0	1,4-Diethylbenzene
9.5	Cyclohexane		

Total Individual Hydrocarbons	$\mu g/m^3$	%		
Σ Olefin	60	15	CH_4(ppm)	2.1
Σ Aromatic	89	22	CO(ppm)	1.6
Σ Paraffin	255	63	$CFCl_3$(ppt)	556
TOTAL	404		CCl_4(ppt)	1218

-- Less than .5$\mu g/m^3$

TABLE 22. HYDROCARBON, HALOCARBON AND CO LEVELS IN SAMPLE A-3 COLLECTED N. OF HOUSTON (1250') AT 4:00 PM ON JULY 8, 1976.

µg/m³	Hydrocarbon	µg/m³	Hydrocarbon
8.5	Ethane	3.0	2,3-Dimethylpentane
--	Ethylene	7.0	3-Methylhexane
6.5	Acetylene	2.0	2,2,3-Trimethylpentane
28.5	Propane	2.0	n-Heptane
3.0	Propene	1.5	Methylcyclohexane
25.0	i-Butane	1.0	2,4-Dimethylhexane
24.5	n-Butane	--	2,3,4-Trimethylpentane
1.0	1-Butene	11.5	Toluene
1.5	i-Butene	1.0	2,3-Dimethylhexane
1.0	t-2-Butene	4.0	2-Methylheptane
--	c-2-Butene	2.5	3-Ethylhexane
21.5	i-Pentane	1.0	n-Octane
13.0	n-Pentane	--	Ethylcyclohexane
3.0	1-Pentene	3.0	Ethylbenzene
--	t-2-Pentene	4.0	p & m-Xylene
1.5	c-2-Pentene	1.0	Styrene
2.0	Cyclopentene	3.0	o-Xylene
1.5	Cyclopentane	1.0	n-Nonane
1.0	2,3-Dimethylbutane	--	i-Propylbenzene
6.5	2-Methylpentane	1.0	n-Propylbenzene
1.5	c-4-Methyl-2-Pentene	2.0	p-Ethyltoluene
5.0	3-Methylpentane	--	m-Ethyltoluene
--	1-Hexene	1.0	o-Ethyltoluene
7.0	n-Hexane	2.0	1,3,5-Trimethylbenzene
--	t-2-Hexene	1.5	1,2,4-Trimethylbenzene
--	c-2-Hexene	1.0	1,2,3-Trimethylbenzene
2.5	Methylcyclopentane	1.0	Methylstyrene
1.0	2,4-Dimethylpentane	--	1,3-Diethylbenzene
10.0	Benzene	1.5	1,4-Diethylbenzene
7.5	Cyclohexane		

Total Individual Hydrocarbons	µg/m³	%		
Σ Olefin	14.5	6	CH_4(ppm)	2.2
Σ Aromatic	43.5	18	CO(ppm)	.9
Σ Paraffin	179	76	$CFCl_3$(ppt)	290
TOTAL	237		CCl_4(ppt)	597

-- Less than .5µg/m³

* Value questionable

TABLE 23. HYDROCARBON LEVELS IN 6-9 AM WSU TRAILER SAMPLE ON JULY 8, 1976.

$\mu g/m^3$	Hydrocarbon	$\mu g/m^3$	Hydrocarbon
19.0	Ethane	14.5	2,3-Dimethylpentane
20.0	Ethylene	14.0	3-Methylhexane
20.0	Acetylene	8.5	2,2,3-Trimethylpentane
46.0	Propane	8.5	n-Heptane
26.0	Propene	7.5	Methylcyclohexane
51.0	i-Butane	3.0	2,4-Dimethylhexane
69.0	n-Butane	--	2,3,4-Trimethylpentane
6.0	1-Butene	35.0	Toluene
8.0	i-Butene	1.5	2,3-Dimethylhexane
10.0	t-2-Butene	6.0	2-Methylheptane
--	c-2-Butene	5.0	3-Ethylhexane
90.0	i-Pentane	3.5	n-Octane
45.5	n-Pentane	3.5	Ethylcyclohexane
6.0	1-Pentene	7.5	Ethylbenzene
--	t-2-Pentene	20.0	p & m-Xylene
--	c-2-Pentene	4.5	Styrene
4.5	Cyclopentene	11.5	o-Xylene
6.5	Cyclopentane	3.5	n-Nonane
7.0	2,3-Dimethylbutane	1.5	i-Propylbenzene
24.0	2-Methylpentane	3.5	n-Propylbenzene
6.0	c-4-Methyl-2-Pentene	9.0	p-Ethyltoluene
21.5	3-Methylpentane	--	m-Ethyltoluene
4.0	1-Hexene	4.0	o-Ethyltoluene
16.0	n-Hexane	5.0	1,3,5-Trimethylbenzene
2.0	t-2-Hexene	9.5	1,2,4-Trimethylbenzene
--	c-2-Hexene	3.5	1,2,3-Trimethylbenzene
11.0	Methylcyclopentane	1.5	Methylstyrene
4.0	2,4-Dimethylpentane	1.0	1,3-Diethylbenzene
18.0	Benzene	2.0	1,4-Diethylbenzene
11.0	Cyclohexane		

Total Individual Hydrocarbons	$\mu g/m^3$	%	
Σ Olefin	92.5	13	CH_4(ppm)
Σ Aromatic	137	19	CO(ppm)
Σ Paraffin	500.5	68	$CFCl_3$(ppt)
TOTAL	730		CCl_4(ppt)

-- Less than .5$\mu g/m^3$

Hydrocarbon changes from morning to afternoon are supportive of photochemical oxidant production on July 8. Table 24 lists various hydrocarbon/acetylene ratios in the morning air mass west of Houston and in the more aged air mass found in the same area during the afternoon hours. The ratios all show a decrease in the aged air mass, as would be expected. Benzene shows the least change, which is in agreement with smog chamber experiments that have shown it to be unreactive in atmospheric photochemical simulation experiments. Olefins with a 69% decrease in ratio showed the largest change, followed by aromatics at 36% and paraffins with an 8% loss. The relative order of change for these three hydrocarbon classes is consistent with that predicted from chamber experiments.

Very little aerometric data have been published with which we can compare the data in Table 24. This is especially true of cases in which the same air mass was followed throughout the diurnal period. Calvert (20) has provided an indepth analysis of LARPP data collected in Los Angeles on November 5, 1973. He established a fractional removal rate for propene of about 8% hr.$^{-1}$ based on aircraft data collected between 8 am and 2 pm. Based on the data in Table 24, propene disappeared at a rate of about 11% hr.$^{-1}$ in Houston between 10 am and 4 pm on July 8, 1976. The two numbers agree fairly well considering the differences in meteorology, light intensity, etc., that certainly existed.

TABLE 24. HYDROCARBON-ACETYLENE RATIOS IN MORNING AND AFTERNOON AIR MASSES ON JULY 8, 1976.

	AM	PM	% Change
propene/acetylene	1.6	.5	-68
2-methylpentane/acetylene	1.2	1.0	-17
benzene/acetylene	1.6	1.5	- 6
toluene/acetylene	3.2	1.7	-47
Σolefins/acetylene	7.0	2.2	-69
Σaromatic/acetylene	10.5	6.7	-36
Σparaffins/acetylene	30.0	27.5	- 8

OXIDES OF NITROGEN

The nitric oxide record at the northwest Houston sampling site resembled the diurnal pattern generally observed in urban areas. The highest hourly average was normally observed during the 6 to 9 am rush traffic period. Peak levels that often approached 100 ppb during the morning injection period decreased rapidly to the 25 ppb range or less by early afternoon. On afternoons when high oxidant levels were recorded at the northwest sampling site, nitric oxide levels were below 5 ppb.

With the exception of a few periods during the last week of the study, nitrogen dioxide concentrations seldom exceeded 50 ppb at the WSU trailer site. Daily NO_2 peak concentrations were commonly observed during the mid-afternoon hours. Hourly average NO_2 and NO readings at the northwest Houston site are tabulated on a daily basis in Appendix A.

Oxides of nitrogen measurements are important because of the integral part NO and NO_2 play in atmospheric photochemical processes. The amount of ozone produced is significantly affected by the hydrocarbon to NO_x ratio. In NO_x rich atmospheres ($Hc/NO_x < 5$) oxidant production is retarded, however, when the hydrocarbon and NO_x mixture exists in proportions of about 10 to 1 conditions are optimum for secondary pollutant production. Figure 25 shows a plot of the 6 to 9 am hydrocarbon and NO_x concentrations recorded at ground level in northwest Houston. In most instances the Hc/NO_x ratio fell in the range of 7.5 to 18.5 with the average being about 11.5. How representative this value is of the Houston area in general is difficult to assess. We did not operate continuous NO_x monitors at the north and south Houston hydrocarbon sampling sites. However, a NO_x reading was made on the Teflon bag samples collected for hydrocarbon analysis at these two sites. Based on about 10 samples from each location the Hc/NO_x ratio in south Houston averaged 30, while that at the north site averaged 83. We feel that a higher Hc/NO_x ratio should be observed at these two sites, because they are closer to the ship channel chemical complex; however, the absolute magnitude should be considered with caution because of the bag sampling method utilized may have resulted in some loss of NO_x on the walls.

The real time NO_x monitor carried aboard the aircraft provided a means of acquiring information concerning hydrocarbon/NO_x ratios at various loca-

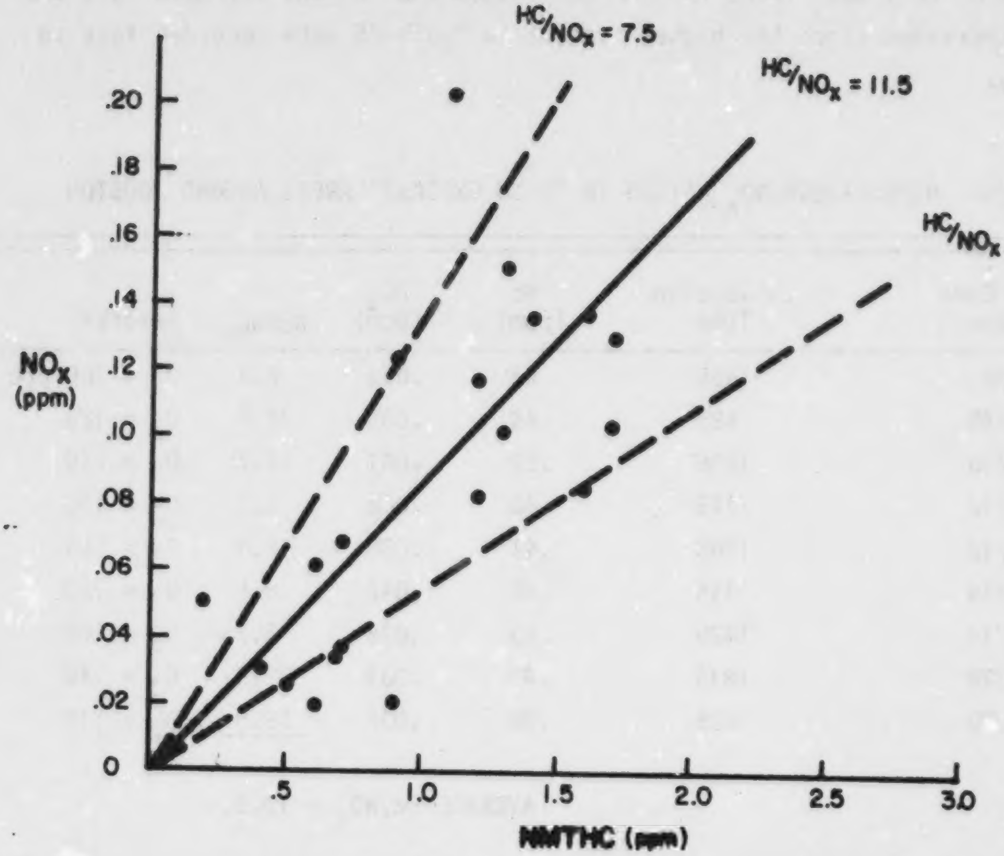


Figure 25. Ground level 6-9 am hydrocarbon and NO$_x$ concentrations recorded at the WSU trailer site.

tions and altitudes over Houston. Table 25 provides a summary of the ratio observed in air masses exhibiting photochemical activity. It can be seen that the average Hc/NO_x ratio recorded in these "high ozone" areas is essentially the same as the average determined at ground level in NW Houston between 6 and 9 am. There is some indication that as the air mass ages the ratio increases since the highest ratios in Table 25 were recorded late in the day.

TABLE 25. HYDROCARBON/NO_x RATIOS IN "HIGH OXIDANT" AREAS AROUND HOUSTON

Sample Code and Date	Collection Time	Hc (ppm)	NO_x (ppm)	Hc/NO_x	Remarks
A-3 7/8	1555	.45	.053	8.4	O_3 = 200 ppb
A-1 7/10	1525	.44	.035	12.6	O_3 = 125
A/2 7/10	1536	.52	.041	12.7	O_3 = 110
A-3 7/12	1115	.40	.048	8.3	O_3 = 110
A-4 7/12	1705	.41	.030	12.4	O_3 = 186
A-2 7/14	1415	.41	.042	8.5	O_3 = 120
A-3 7/14	1428	.63	.078	8.1	O_3 = 100
A-2 7/20	1815	.43	.035	12.3	O_3 = 140
A-3 7/20	1825	.28	.018	15.5	O_3 = 110
		AVERAGE Hc/NO_x = 10.9			

Several other categories of interest as far as hydrocarbon/NO_x ratios are concerned are listed in Table 26. These data were collected on aircraft flights throughout the study period. The background and petrochemical categories exhibit higher hydrocarbon/NO_x ratios (28 and 24) than the ratio (12) in samples collected over or downwind of the Houston urban area during the early morning hours. It should be noted that the number of samples in each of the three classifications is small and consequently more data would be required for highly reliable averages.

TABLE 26. HYDROCARBON/NO_x RATIOS IN VARIOUS TYPES OF AIR MASSES.

	AVERAGE HC/NO_x RATIO	No. of Samples
Background Air	28	2
Urban Plume (Low Ozone)	12	4
Refinery Plume	24	4

HALOCARBONS

Fluorocarbon-11, methyl chloroform (1,1,1-trichloroethane), carbon tetrachloride, fluorocarbon-113, chloroform and trichloroethylene concentrations were monitored continuously at the sampling site in northwest Houston. The ambient concentrations of these halocarbon species were also determined in aircraft collected samples and some ground level grab samples. Table 27 provides a summary of various halocarbon data sets. The individual measurements used to arrive at the averages in Table 27 are tabulated in Appendix A.

Ambient fluorocarbon-11 concentrations at the ground level trailer site were generally highest during the early morning hours. We calculated an average concentration of 649 ppt for the period from 0100 to 0800. This compares to 405 ppt during the midday period and 509 ppt during the evening hours. This range of about 400 to 650 ppt for F-11 is similar to that measured in the Los Angeles atmosphere. For example, Simmonds, et al., (21) reported an average F-11 concentration of 650 ppt during a three day sampling program conducted at various sites in the Los Angeles Basin.

The average ambient F-11 concentrations at ground level in Houston generally exceeded the tropospheric background level ∿ 140 ppt by at least a factor of three. This difference provides a basis for using F-11 as a tracer of man's activities. The 258 ppt average F-11 concentration in air masses containing elevated ozone (Table 27) is well above the background level. Furthermore, all of the samples included in the high ozone category of Table 27 exhibited F-11 concentrations greater than 190 ppt with several approaching 300 ppt. These data support the earlier stated contention that anthropogenic precursors were the primary source of oxidants measured in and around Houston during July, 1976. F-11 emissions in the Houston area appear to differ somewhat on weekdays and weekends. As can be seen in Table 27, weekend averages were approximately 15% lower than those recorded during the week.

The ambient CCl_4 concentrations measured in the Houston vicinity are higher than the levels recorded in Los Angeles. An average concentration of 220 ppt was reported in the Los Angeles Basin study referred to previously (21). Table 27 shows that ground level CCl_4 exhibited little diurnal variation. When all sampling days are considered, there is less than 25 ppt difference between the early morning, midday and evening averaging periods. This diurnal behavior seems to imply that an increase in CCl_4 emissions occurs durring normal working hours. It can be seen in Table 27 that the highest average was recorded during the 9 am to 4 pm period on weekdays.

If the diurnal emission rate was relatively constant, a decrease in concentration would be expected during midday when atmospheric mixing is at a maximum.

VISIBILITY AND PARTICLES

The relationship between visibility and ozone concentration in the Houston atmosphere has been reported to vary considerably. On some occasions, reduced visibility will coincide with elevated ozone levels. However, at other times, episode ozone conditions will exist and yet visibility will be good. The opposite also appears to be true, since there are times when visibility is restricted and ozone levels are low. These findings have provided a basis for the argument that chemical transformations in the Houston atmosphere differ from those in the Los Angeles Basin (22).

Our airborne data indicates that a positive correlation always existed between enhanced ozone levels and decreased visibility in the plume downwind of Houston. Figure 26 shows data recorded during a pass across the plume at a distance of about 90 miles from Houston on the afternoon of July 12 (see darkened line in Figure 22). Maxima and minima in the b_{scat} and ozone curves

TABLE 27. HALOCARBON CONCENTRATIONS IN THE HOUSTON AREA.

	$CFCl_3$	CH_3CCl_3	CCl_4
ALL DAYS AT TRAILER SITE			
0100 - 0800	649	964	369
0900 - 1600	405	680	349
1700 - 2400	509	910	345
WEEKDAYS AT TRAILER SITE			
0100 - 0800	683	1214	365
0900 - 1600	432	908	385
1700 - 2400	526	1230	354
WEEKENDS AT TRAILER SITE			
0100 - 0800	565	495	375
0900 - 1600	336	253	282
1700 - 2400	468	312	327
AIRCRAFT SAMPLES COLLECTED IN "BACKGROUND" AIR			
	176	---	218
AIRCRAFT SAMPLES COLLECTED IN HIGH OZONE			
	258	---	502

are coincidental. Figure 27 provides a second example of this type of visibility-ozone correlation. Data in this graph were collected on the same flight about 45 miles from Houston. Measurements in the main section of the plume show both high ozone and high scattering coefficient. This relationship persists in the vertical plume profile as well. Figure 28 shows that ozone and b_{scat} values are highest in the 3000 feet immediately above the surface and then both decrease in the region from 3000 to 5000 feet.

In air masses directly over Houston, there were occasions when the correlation between high ozone and elevated b_{scat} readings was not as good. Figure 29 shows a case where the greatest degradation in visibility was displaced somewhat from the region of highest ozone. The reason for this appears to be that the section of the plume with highest b_{scat} values also contained high NO_x levels which scavenged a significant portion of the ozone. This behavior is not entirely unexpected in the region close to ship channel emission sources, since the air mass has not had time to become completely mixed.

Filter tapes for sulfate analysis were collected during five aircraft flights. Several seven minute integrated samples were obtained on each of the five flights. Sulfate concentrations were found to vary from less than 0.1 to 10.8 $\mu g/m^3$. Since the samples were collected over distances of about 15 miles, it is difficult to relate high sulfate readings to specific sources, however, it does seem that the highest sulfate levels were recorded in areas downwind of the ship channel industrial area. Figure 30 shows the location of sulfate samples collected during the afternoon flight on July 22. Winds on that afternoon were from the southeast (110-130°). Sample #3 which was collected to the southeast of Baytown (upwind) contained the least sulfate (< 0.1 $\mu g/m^3$) while samples 2, 4 and 5, which were obtained in the region influenced to the greatest extent by the industrial plume, contained up to 10 $\mu g/m^3$ of sulfate. The two samples collected further to the west (#1 and #6) contained less than 1 $\mu g/m^3$ sulfate. These latter two samples probably represent emissions emanating more from the downtown Houston area.

Sulfate data collected on other days differed very little from that just described for July 22. Concentrations never exceeded 11 $\mu g/m^3$ and for the most part, ranged from 0.5 to 6.0 $\mu g/m^3$.

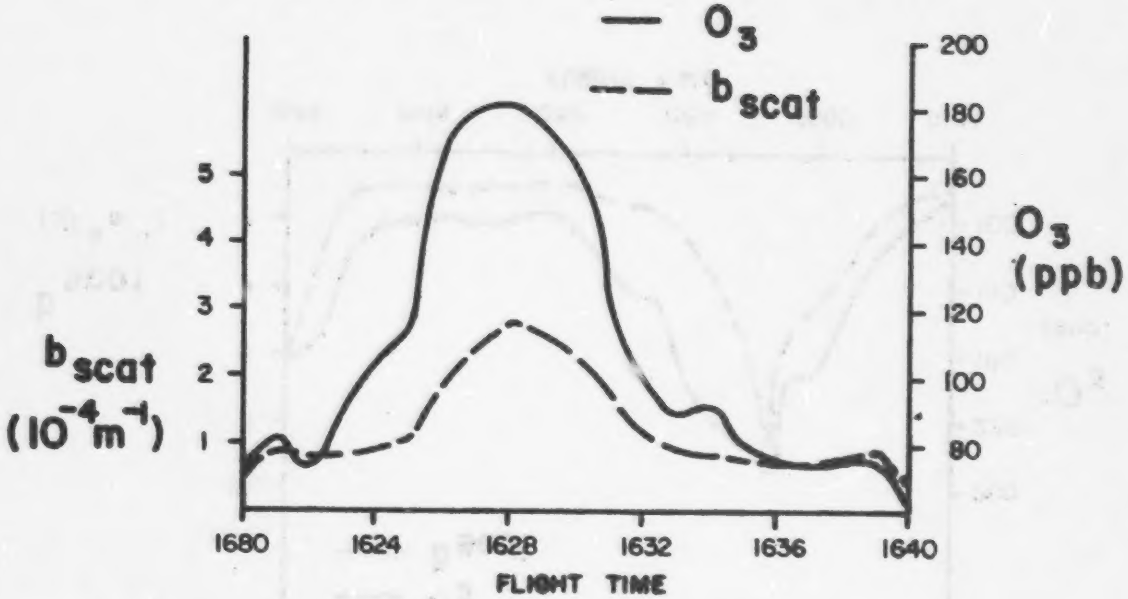


Figure 26. Relationship between ozone concentration and b_{scat} values in plume approximately 90 miles downwind Houston (Flt. #10; July 12, 1976).

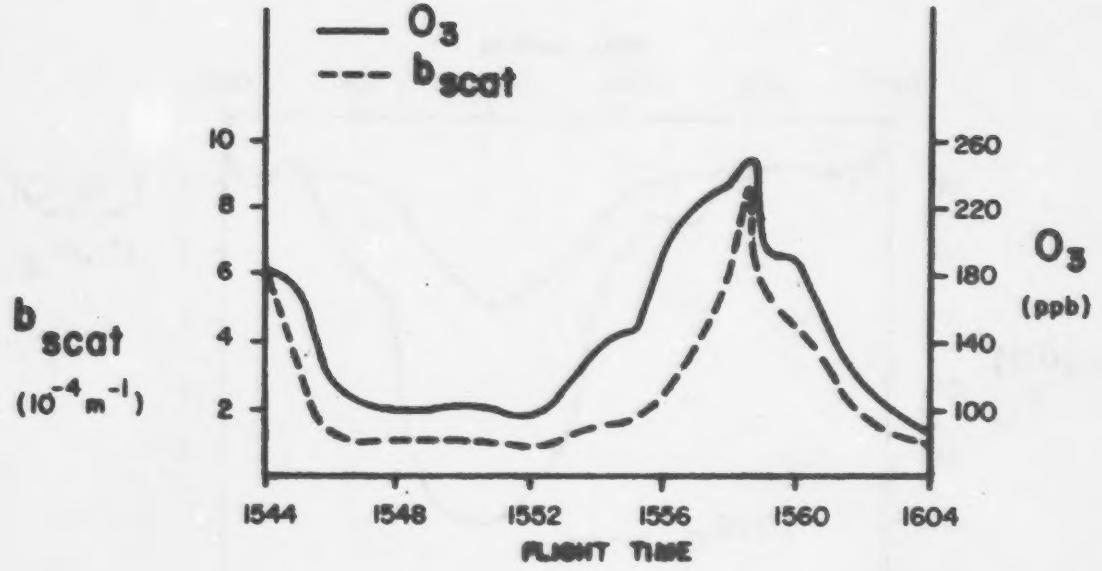


Figure 27. Relationship between ozone concentration and b_{scat} values in plume approximately 45 miles downwind Houston (Flt. #10; July 12, 1976).

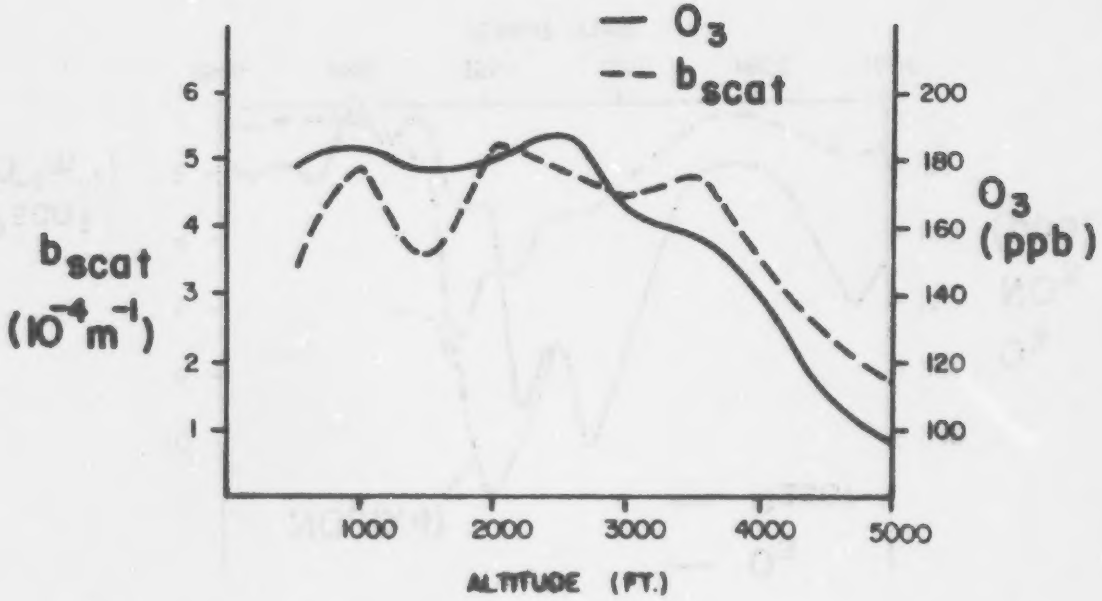


Figure 28. Relationship observed between ozone concentration and b_{scat} values during vertical sounding in Houston plume (Flt. #10; July 12, 1976.

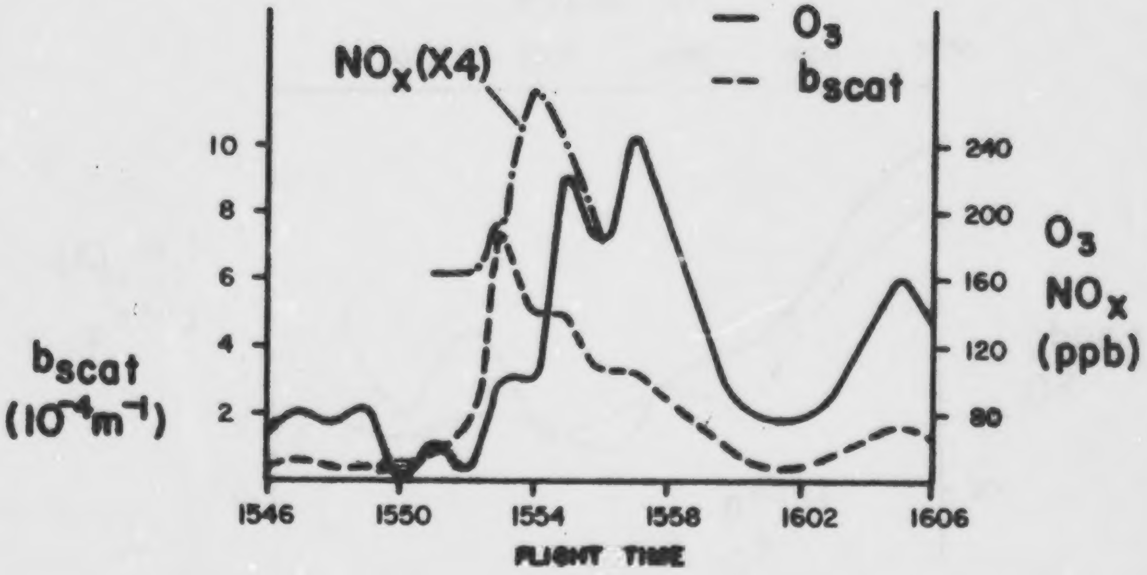
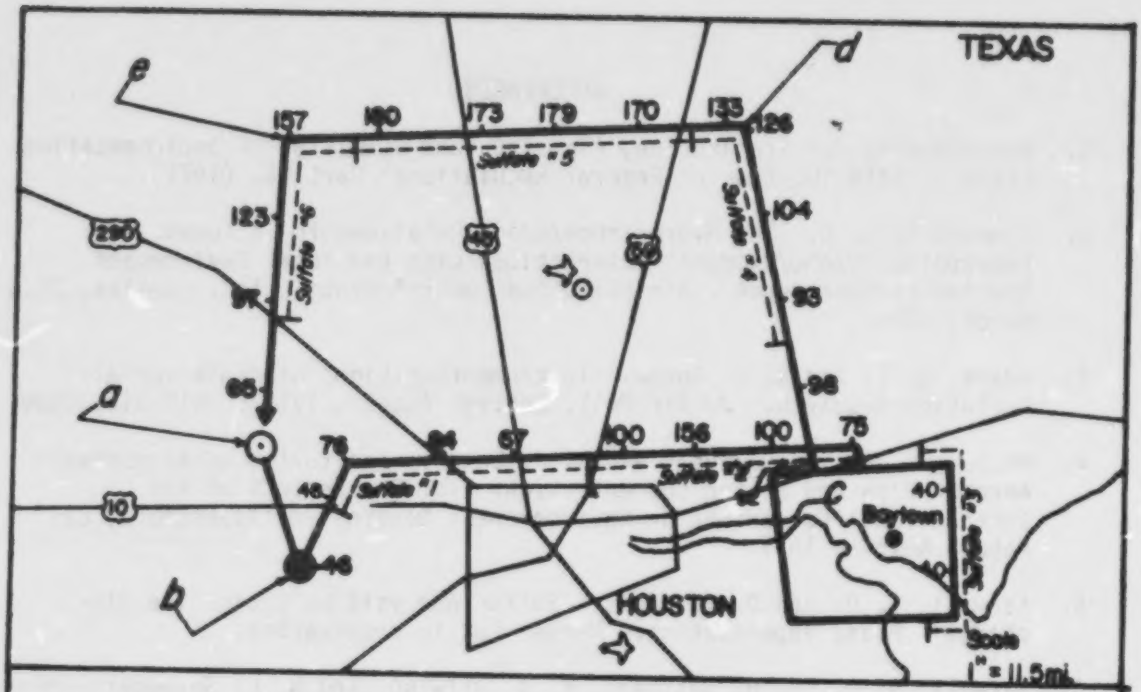


Figure 29. Relationship between ozone concentration and b_{scat} values directly over Houston (Flt. #7; July 8, 1976).


TEXAS
e
d
157
160
173
179
170
135
126
Sulfate #5
123
Sulfate #4
Sulfate #6
104
290
45
59
97
93
98
65
a
76
84
67
100
156
100
75
Sulfate #1
Sulfate #2
Sulfate #3
46
10
c
40
Baytown
40
b
46
HOUSTON
Scale
1" = 11.5 mi.

	μg/m^3		μg/m^3
Sulfate #1	0.2	Sulfate #4	2.0
Sulfate #2	1.7	Sulfate #5	10.1
Sulfate #3	<0.1	Sulfate #6	0.7

Figure 30. Sulfate data obtained during the afternoon of July 22, 1976 (Flt #26 - see Appendix B for details).

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APPENDIX A

Ozone, nitric oxide, nitrogen dioxide, non-methane total hydrocarbon, carbon monoxide, methane, fluorocarbon-11, carbon tetrachloride and methyl chlorofrom concentrations recorded at the WSU trailer site are listed in this section. Meteorological parameters including wind speed, wind direction, temperature, dew point, relative humidity, solar radiation and barometric pressure are also tabulated. The data are compiled on a daily basis and recorded as hourly averages. Time is Central Daylight Time.

TABLE A1. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 1, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	--	--	--	--	--	--	--	--	--	4	190	12	76	--	0	29.99
0200	--	--	--	--	--	--	--	--	--	4	190	14	75	--	0	30.00
0300	--	--	--	--	--	--	--	--	--	6	190	10	74	--	0	30.00
0400	1	15	14	--	--	--	--	--	--	10	70	10	74	--	0	30.02
0500	1	12	12	--	--	--	--	--	--	7	120	8	74	--	0	30.01
0600	4	20	30	--	--	--	--	--	--	6	190	23	76	--	0	30.01
0700	4	37	37	--	--	--	--	--	--	5	190	23	76	--	103	30.02
0800	5	54	40	--	--	--	--	--	--	7	190	25	81	--	389	30.02
0900	15	20	19	--	--	--	--	--	--	9	220	22	85	--	696	30.02
1000	21	10	6	--	--	--	--	--	--	11	220	12	87	--	805	30.03
1100	27	10	3	--	--	--	--	--	--	8	240	13	91	--	985	30.03
1200	38	9	2	--	--	--	--	--	--	5	210	21	93	68	1360	30.01
1300	52	9	4	--	--	--	--	--	--	8	200	18	94	67	1348	29.99
1400	49	8	5	--	--	--	--	--	--	10	200	21	95	67	1391	29.98
1500	32	13	6	--	--	--	--	--	--	11	190	23	93	67	873	29.99
1600	28	12	4	--	--	--	--	--	--	15	190	27	93	67	761	29.99
1700	34	18	8	.6	1.2	2.1	--	--	--	11	190	26	92	66	769	29.98
1800	21	13	8	.6	1.1	2.1	--	--	--	8	190	26	91	66	494	29.98
1900	21	11	9	.5	1.1	2.1	--	--	--	10	190	28	89	66	298	29.97
2000	22	10	13	.7	1.4	2.4	--	--	--	7	190	27	85	66	97	29.99
2100	4	13	13	--	--	--	--	--	--	7	190	24	82	69	0	30.02
2200	0	15	13	1.2	1.4	3.0	--	--	--	7	190	27	80	69	0	30.02
2300	0	13	12	.8	1.3	3.0	--	--	--	8	190	29	79	70	0	30.01
2400	0	9	10	.8	1.1	3.2	--	--	--	9	190	32	78	70	0	30.00

TABLE A2. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 2, 1976

Time	GAS DATA									MET. DATA						
	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	5	6	5	.8	.9	2.5	--	--	--	6	200	25	78	70	0	29.99
0200	9	5	2	.7	.7	2.7	--	--	--	7	200	25	78	71	0	29.98
0300	8	5	3	.7	.6	2.7	--	--	--	4	190	27	77	71	0	29.99
0400	5	7	5	.7	.5	2.8	--	--	--	5	190	25	76	71	0	30.00
0500	6	6	3	.8	.6	2.9	--	--	--	4	180	18	75	70	0	30.00
0600	1	16	11	.7	.7	2.9	--	--	--	5	190	18	74	69	0	30.02
0700	0	67	18	.7	1.2	3.0	--	--	--	4	190	20	77	70	0	30.03
0800	1	59	23	1.2	2.8	3.5	--	--	--	8	200	20	82	71	157	30.04
0900	15	25	14	1.1	2.3	3.4	--	--	--	12	190	29	87	71	348	30.04
1000	22	10	6	1.1	1.1	2.1	--	--	--	15	190	23	90	70	645	30.04
1100	19	10	3	.6	1.0	2.0	--	--	--	12	190	29	90	70	1009	30.04
1200	20	10	3	.2	.8	2.0	--	--	--	14	200	27	92	70	1231	30.04
1300	21	10	3	.3	.9	1.9	--	--	--	13	200	27	91	71	958	30.03
1400	31	19	7	.3	.9	1.9	--	--	--	13	200	26	92	69	1422	30.01
1500	24	14	8	.4	.9	1.8	170	165	227	15	190	30	90	70	1398	30.01
1600	19	12	4	.4	1.1	1.8	236	163	546	15	190	29	91	69	756	30.00
1700	19	16	7	.4	1.2	1.8	219	159	700	14	190	26	90	69	1006	30.00
1800	17	14	4	.5	1.1	1.8	153	151	261	12	200	30	90	70	969	30.00
1900	9	12	7	--	--	--	265	168	225	8	180	32	82	69	778	29.99
2000	4	11	9	--	--	--	214	--	--	9	180	27	80	71	92	29.99
2100	4	9	9	--	--	--	203	--	--	7	190	28	79	71	0	29.99
2200	4	8	9	--	--	--	208	128	204	7	190	32	79	71	0	30.02
2300	6	7	8	--	--	--	285	86	533	7	180	30	78	71	0	30.03
2400	4	6	9	.7	.9	2.9	198	151	137	5	170	30	78	71	0	30 04

TABLE A3. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 3, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	7	5	7	.6	.8	2.0	201	156	651	7	170	28	78	71	0	30.03
0200	6	5	6	.6	.7	1.9	183	154	411	5	170	25	77	71	0	30.03
0300	6	5	5	.6	.6	1.9	251	159	164	4	160	20	77	72	0	30.02
0400	5	5	7	.5	.6	1.9	217	172	741	4	180	22	76	72	0	30.02
0500	5	6	6	.5	.7	2.0	219	170	561	5	180	24	76	72	0	30.03
0600	4	9	10	.9	.8	2.0	216	166	753	6	190	23	79	72	157	30.03
0700	11	11	9	.9	.9	2.0	300	242	117	7	190	33	84	73	434	30.06
0800	16	11	7	1.1	1.1	2.0	266	398	213	8	190	26	86	73	626	30.06
0900	20	11	4	1.1	1.0	2.1	208	272	130	8	190	29	87	73	753	30.07
1000	21	10	3	.8	.9	2.1	174	465	247	15	190	31	89	73	879	30.06
1100	21	9	4	.6	.8	2.2	201	255	107	10	200	22	89	73	942	30.06
1200	24	8	4	.6	.8	2.1	199	291	91	15	190	27	90	73	681	30.05
1300	24	8	4	.3	.8	2.0	205	181	126	14	190	8	91	73	1250	30.04
1400	26	8	3	.3	.9	2.0	221	236	209	23	190	18	93	72	1005	30.03
1500	20	10	5	.4	1.1	2.0	222	167	112	13	190	31	90	74	768	30.00
1600	12	9	4	.3	1.0	2.0	232	175	90	17	230	23	79	74	334	30.04
1700	9	16	8	.3	1.1	2.0	241	230	201	calm		27	85	76	693	30.01
1800	5	15	9	1.3	1.4	2.2	250	505	449	10	190	19	82	74	200	29.99
1900	0	23	12	1.1	1.7	2.2	297	403	367	8	190	22	82	75	127	30.00
2000	0	13	8	.8	1.7	2.2	313	167	115	5	190	26	82	74	48	30.01
2100	0	12	8	.9	1.4	2.2	329	180	190	8	190	27	81	73	0	30.00
2200	0	10	5	1.2	1.3	2.1	999	174	153	5	190	23	80	73	0	30.02
2300	0	16	8	.2	1.2	2.2	443	231	108	6	190	27	80	73	0	30.02
2400	0	12	8	.2	1.1	1.8	354	245	115	7	190	30	80	73	0	30.02

TABLE A4 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 4, 1976

				GAS	DATA							MET.	DATA			
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	13	13	.3	1.1	1.9	301	380	271	5	190	26	79	73	0	30.02
0200	0	12	10	.2	1.0	2.0	400	339	138	6	180	22	78	73	0	30.02
0300	0	7	6	.3	.8	2.2	275	267	128	6	190	24	78	73	0	30.01
0400	0	4	4	.4	.6	2.4	298	246	225	4	190	21	77	73	0	30.01
0500	--	--	--	.5	.5	2.4	286	232	170	4	180	--	--	--	--	30.01
0600	0	10	5	.6	.7	2.6	335	241	191	calm		9	75	72	10	30.03
0700	0	26	7	.8	1.6	2.9	439	226	1022	4	160	8	76	73	108	30.03
0800	1	13	6	.6	1.1	3.0	515	846	418	3	210	21	82	74	378	30.05
0900	3	8	2	.5	.9	2.9	291	183	100	5	190	25	85	74	461	30.05
1000	5	7	1	.4	.8	2.9	320	182	80	7	190	27	86	77	580	30.05
1100	9	6	1	.2	.6	2.3	286	189	223	8	170	29	87	72	692	30.05
1200	12	7	1	.2	.7	2.1	236	173	148	7	200	24	90	72	1146	30.05
1300	28	9	3	.2	.8	2.0	211	182	174	6	190	24	91	71	915	30.02
1400	31	5	3	.2	.7	2.0	303	177	165	10	190	21	92	69	898	30.01
1500	36	6	2	.2	.7	2.0	222	209	287	9	190	21	93	69	1017	29.99
1600	36	7	3	.2	.7	2.0	199	267	272	8	190	17	94	70	895	29.98
1700	--	--	--	.2	.7	2.0	197	361	169	10	190	--	--	--	--	29.98
1800	17	8	7	.3	1.1	2.1	311	225	299	7	190	32	87	71	171	29.98
1900	19	8	13	.4	1.2	2.2	364	255	306	7	190	22	84	71	67	29.98
2000	9	11	22	.4	1.2	2.2	325	274	179	5	190	22	82	69	28	29.98
2100	--	--	--	.4	1.1	2.2	1196	237	187	4	180	--	--	--	--	29.98
2200	4	16	19	.4	1.6	2.2	458	215	148	3	180	14	77	69	0	30.00
2300	0	15	21	.5	1.4	2.2	290	212	118	calm		12	76	68	0	30.00
2400	0	15	21	.6	1.4	2.2	341	215	226	calm		17	76	68	0	30.00

TABLE A5. SURVACE DATA COLLECTED AT HOUSTON, TX, ON JULY 5, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	25	21	.6	1.6	2.2	603	213	259	3	190	13	76	69	0	29.99
0200	--	--	--	.6	2.1	2.2	684	332	353	4	250	--	--	--	--	29.98
0300	0	38	11	.8	2.0	2.2	753	575	608	4	190	8	76	71	0	29.97
0400	0	34	15	.8	1.9	2.2	701	368	917	calm		14	76	71	0	29.96
0500	0	31	14	.7	1.7	2.2	786	312	598	calm		10	75	70	0	29.97
0600	0	30	14	.7	1.5	2.2	589	283	310	calm		11	76	70	0	29.98
0700	0	28	10	.7	1.4	2.2	366	264	363	4	350	15	76	70	62	30.00
0800	0	27	7	.7	1.3	2.2	324	301	395	10	360	14	78	71	231	30.01
0900	5	19	5	.6	1.0	2.2	299	445	379	4	330	14	81	72	432	30.00
1000	--	--	--	.4	.6	2.0	191	232	408	6	50	--	--	--	--	30.01
1100	--	--	--	.4	.6	2.0	187	220	131	8	220	--	--	--	--	30.03
1200	--	--	--	.4	.8	1.9	400	277	214	4	50	--	--	--	--	30.02
1300	10	10	13	.3	.8	1.9	358	242	273	7	360	18	73	68	200	30.01
1400	11	12	10	.3	.7	1.9	211	221	137	10	20	--	--	--	--	30.02
1500	11	14	7	.2	.8	2.0	272	223	162	7	50	18	74	70	440	30.00
1600	13	14	10	.3	1.0	2.0	326	208	182	7	40	25	76	70	591	29.98
1700	14	15	17	.3	1.3	2.2	450	225	240	6	60	25	77	70	377	29.97
1800	--	--	--	.3	1.4	2.1	334	238	354	8	140	--	--	--	--	29.98
1900	--	--	--	.5	1.5	2.2	377	263	238	10	90	--	--	--	--	29.98
2000	5	21	34	.7	1.9	2.2	1771	323	261	8	150	18	78	68	116	29.97
2100	0	38	41	.8	2.4	2.2	555	1056	250	5	60	18	74	68	55	29.97
2200	0	52	30	.9	.25	2.4	1100	545	314	4	180	16	74	69	0	29.97
2300	0	48	23	.9	2.5	2.5	772	1438	2041	calm		16	73	69	0	29.99
2400	0	38	24	.9	2.5	2.6	664	1303	561	calm		13	73	69	0	29.99

TABLE A6. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 6, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	27	20	.7	2.2	2.6	829	595	247	calm		11	73	69	0	29.99
0200	0	15	17	.7	1.7	2.6	479	394	243	calm		12	73	70	0	29.99
0300	0	19	15	.7	1.6	2.6	691	397	229	4	30	9	73	70	0	29.97
0400	0	15	14	.7	1.3	2.6	790	391	228	4	30	9	73	69	0	29.96
0500	0	15	10	.7	1.1	2.6	335	365	178	5	30	12	73	69	0	29.96
0600	0	18	9	.6	1.1	2.5	218	322	153	4	50	14	73	69	0	29.99
0700	0	55	12	.6	2.2	2.5	366	366	138	7	40	14	73	69	80	29.99
0800	0	55	13	.7	2.6	2.5	445	386	159	8	40	16	74	70	194	29.99
0900	2	28	11	.3	1.8	2.3	396	606	191	10	60	16	77	71	673	30.01
1000	8	15	8	.3	1.4	2.2	365	448	153	10	50	18	81	71	974	30.01
1100	21	10	8	.3	1.1	2.0	606	416	221	9	90	19	82	71	914	30.01
1200	39	10	8	.5	.9	2.0	237	237	231	9	120	20	82	70	973	30.00
1300	43	7	10	.3	1.1	2.0	318	234	191	7	160	23	85	70	801	30.00
1400	37	6	7	.4	.9	1.9	463	230	209	7	90	23	86	70	854	29.99
1500	38	8	9	.4	1.1	1.9	236	534	388	9	70	26	85	69	832	29.97
1600	23	13	18	.6	1.2	1.9	301	347	262	8	70	22	82	69	873	29.96
1700	13	20	25	.4	1.6	2.0	313	395	311	11	130	22	83	69	526	29.95
1800	10	21	33	.4	2.0	2.0	425	265	264	8	100	20	82	68	329	29.96
1900	2	27	37	.6	2.1	2.1	594	286	283	8	170	21	80	70	150	29.98
2000	0	22	36	.6	2.0	2.1	401	423	443	4	190	22	79	69	42	29.99
2100	0	19	26	.6	1.9	2.1	348	915	412	4	190	23	77	69	0	29.99
2200	0	25	24	.6	1.7	2.1	399	542	455	3	100	18	76	68	0	30.00
2300	0	38	24	.6	2.1	2.2	591	242	491	6	40	13	76	69	0	30.00
2400	0	34	24	.6	2.0	2.2	653	436	391	4	40	14	75	70	0	29.99

TABLE A7. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 7, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	8	15	.5	1.5	2.2	964	278	323	4	20	15	74	69	0	29.98
0200	0	14	14	.4	1.2	2.2	395	237	218	calm		13	73	69	0	29.97
0300	0	11	12	.4	1.0	2.2	516	247	326	calm		18	73	69	0	29.98
0400	0	6	12	.4	.8	2.2	440	264	256	calm		11	73	69	0	29.99
0500	0	10	12	.4	.8	2.2	378	274	218	calm		12	72	69	0	30.00
0600	0	27	12	.4	1.0	2.2	283	288	226	5	40	12	72	68	0	30.02
0700	0	57	15	.5	2.1	2.2	593	296	321	5	30	16	73	69	85	30.03
0800	31	45	17	.6	2.8	2.2	402	337	296	8	60	17	76	70	284	30.05
0900	21	21	15	.4	2.4	2.0	--	--	--	8	50	20	79	70	483	30.06
1000	18	9	9	.4	1.1	2.0	--	--	--	4	60	21	83	70	931	30.05
1100	32	7	9	.4	.9	2.0	--	--	--	3	90	18	85	70	912	30.06
1200	34	7	8	.4	.9	2.1	--	--	--	4	50	23	85	69	880	30.05
1300	33	5	8	.4	1.0	2.1	328	268	546	6	140	22	87	68	701	30.04
1400	44	4	17	.3	1.1	2.1	358	279	712	8	180	17	80	70	242	30.03
1500	38	5	22	.3	1.4	2.2	464	284	632	7	130	13	81	73	276	30.03
1600	48	8	30	.3	1.9	2.2	561	313	2110	13	180	20	85	72	559	30.02
1700	44	13	28	.4	1.7	2.0	302	292	372	11	190	27	87	69	493	30.03
1800	30	12	33	.4	1.9	2.1	318	407	364	12	190	25	83	69	296	30.03
1900	10	11	15	.4	1.6	2.1	365	195	328	7	190	33	79	69	120	30.03
2000	5	12	17	.4	1.4	2.1	319	281	348	calm		30	76	68	32	30.03
2100	0	19	20	.3	1.5	2.2	471	233	998	3	190	24	75	69	0	30.03
2200	0	30	20	.4	1.9	2.2	516	280	7032	calm		11	74	69	0	30.04
2300	0	51	20	.6	2.1	2.2	790	293	2718	calm		8	74	69	0	30.04
2400	0	55	20	.7	2.3	2.4	717	270	1062	calm		10	74	69	0	30.04

TABLE A8. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 8, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	52	18	.8	2.5	2.6	808	235	958	calm		5	73	69	0	30.04
0200	0	58	18	.7	2.5	2.8	1056	256	785	calm		7	72	69	0	30.04
0300	0	66	18	.8	2.7	2.7	1016	387	905	calm		8	72	68	0	30.03
0400	0	70	14	.9	2.7	2.7	1167	354	957	calm		5	71	68	0	30.04
0500	0	70	17	.8	2.7	2.7	983	333	797	4	50	7	72	68	0	30.06
0600	0	98	20	.9	2.9	2.7	734	351	697	calm		9	72	68	16	30.06
0700	0	124	28	1.1	4.7	2.7	726	530	503	5	30	10	73	69	74	30.07
0800	0	94	30	.9	4.3	2.5	1025	1034	390	6	50	10	75	70	254	30.08
0900	3	36	33	.8	2.5	2.2	1147	716	256	4	50	14	79	71	402	30.08
1000	16	17	37	.6	2.0	2.2	671	820	234	2	190	18	81	72	489	30.08
1100	40	10	30	.6	1.7	2.2	506	510	1014	3	200	14	85	73	814	30.08
1200	76	6	24	.4	1.5	2.2	436	417	2989	4	230	17	89	71	1160	30.07
1300	108	4	24	.5	1.5	2.2	443	464	2303	4	80	14	89	70	780	30.06
1400	150	4	26	.5	1.7	2.2	505	497	1803	5	80	21	89	70	805	30.03
1500	179	4	20	.5	1.7	2.2	443	464	1085	15	180	17	90	70	791	30.05
1600	136	4	22	.3	1.7	2.0	336	383	481	4	200	20	88	69	257	30.04
1700	50	4	16	.4	1.6	2.0	323	271	270	6	220	12	73	69	53	30.06
1800	25	10	27	.4	2.5	2.0	254	237	4336	5	190	17	73	69	53	30.07
1900	0	14	26	.7	2.1	2.0	352	203	1336	calm		18	76	70	47	30.07
2000	--	--	--	.6	2.0	2.0	406	186	2528	calm		--	--	--	--	30.07
2100	--	--	--	.7	2.1	2.2	536	314	1430	calm		--	--	--	--	30.08
2200	--	--	--	.7	2.1	2.4	1219	223	583	5	50	--	--	--	--	30.09
2300	--	--	--	.8	2.3	2.4	751	219	443	4	40	--	--	--	--	30.08
2400	--	--	--	.7	2.2	2.4	744	210	609	5	50	--	--	--	--	30.06

TABLE A9. SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 9, 1976

				GAS	DATA					MET.	DATA					
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	--	--	--	.8	2.0	2.4	657	221	542	2	30	--	--	--	--	30.05
0200	--	--	--	.7	1.7	2.5	763	311	417	2	20	--	--	--	--	30.04
0300	--	--	--	.8	1.5	2.6	612	292	619	3	40	--	--	--	--	30.05
0400	--	--	--	.8	1.5	2.7	602	306	624	3	40	--	--	--	--	30.06
0500	--	--	--	.7	1.2	2.6	467	282	442	6	50	--	--	--	--	30.07
0600	--	--	--	.6	1.2	2.6	315	256	224	5	40	--	--	--	--	30.08
0700	--	--	--	.5	1.8	2.6	484	222	169	5	50	--	--	--	--	30.09
0800	--	--	--	.6	2.1	2.5	801	203	145	5	350	--	--	--	--	30.11
0900	--	24	4	.8	1.9	2.4	312	205	117	6	30	21	--	71	126	30.11
1000	--	26	3	.9	1.4	2.2	283	210	389	17	180	19	--	72	132	30.12
1100	--	18	5	.6	1.3	2.4	538	206	195	4	70	21	--	73	322	30.14
1200	--	17	8	.7	1.6	2.1	263	255	369	5	180	19	--	68	221	30.14
1300	--	37	7	.5	2.1	2.1	547	280	417	5	190	13	--	69	139	30.13
1400	--	36	8	.8	2.3	2.1	404	325	865	10	160	14	--	71	237	30.11
1500	40	34	13	--	--	--	575	261	590	8	60	18	--	73	310	30.08
1600	18	34	25	--	--	--	581	227	483	5	50	18	--	71	325	30.06
1700	2	20	28	--	--	--	520	725	872	9	130	18	--	71	273	30.05
1800	0	40	30	--	--	--	435	250	284	6	120	20	--	71	215	30.05
1900	0	39	25	--	--	--	488	296	194	6	90	15	--	71	105	30.05
2000	0	37	22	--	--	--	694	302	199	5	50	12	--	72	27	30.05
2100	0	43	22	--	--	--	1038	210	166	7	50	16	--	72	0	30.05
2200	0	18	17	--	--	--	1365	201	229	8	70	16	--	72	0	30.07
2300	0	21	15	.5	2.2	2.6	926	221	278	4	70	16	--	72	0	30.07
2400	0	16	15	.5	1.7	2.6	1067	242	244	4	50	12	--	72	0	30.05

TABLE A10 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 10, 1976

				GAS	DATA							MET.	DATA			
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	15	16	.6	1.6	2.6	771	447	209	calm		14	--	72	0	30.06
0200	0	13	18	.6	1.6	2.6	804	440	293	5	50	13	--	72	0	30.03
0300	0	10	15	.6	1.4	2.6	633	429	251	5	50	16	--	72	0	30.03
0400	0	11	15	.6	1.4	2.8	479	415	454	calm		14	--	72	0	30.04
0500	0	12	13	.6	1.4	2.8	813	462	447	4	50	8	--	72	0	30.06
0600	0	11	12	.6	1.4	2.8	306	489	692	5	130	16	--	72	0	30.07
0700	0	14	15	.6	1.3	2.7	308	791	2233	7	50	16	--	71	21	30.08
0800	0	13	12	.5	1.4	2.7	432	519	235	calm		17	--	71	40	30.12
0900	0	16	17	.4	1.4	2.5	342	239	322	14	20	16	--	71	34	30.12
1000	0	15	19	.5	1.5	2.5	450	725	1729	3	30	18	--	--	56	30.14
1100	8	19	18	.6	1.6	2.5	658	372	205	8	40	21	--	--	221	30.13
1200	3	20	21	.7	1.6	2.5	635	443	233	8	50	19	--	--	451	30.12
1300	14	14	19	.6	1.7	2.2	569	417	237	7	50	21	--	--	552	30.10
1400	12	15	21	.6	1.7	2.2	553	372	213	9	50	20	--	--	590	30.08
1500	12	10	14	.6	1.6	2.2	612	232	208	11	110	20	--	--	528	30.07
1600	11	15	15	.5	1.4	2.1	576	243	152	14	140	18	--	--	628	30.06
1700	19	11	21	.5	1.3	2.0	454	458	175	12	140	21	--	--	577	30.06
1800	17	10	24	.4	1.4	2.1	717	417	159	12	150	18	--	--	163	30.06
1900	16	6	22	.5	1.8	2.1	470	302	195	10	150	16	--	--	90	30.06
2000	7	14	28	.6	2.0	2.2	572	624	208	8	150	17	--	--	28	30.07
2100	0	35	27	.6	2.0	2.3	471	252	275	8	130	19	--	--	8	30.07
2200	0	41	24	.8	1.9	2.3	388	239	450	7	150	20	--	--	0	30.08
2300	0	29	20	.8	1.8	2.4	465	230	238	5	160	21	--	--	0	30.08
2400	0	28	19	.8	1.8	2.5	564	240	297	5	160	15	--	--	0	30.07

TABLE A11 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 11, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	36	15	.8	1.5	2.6	706	286	283	5	170	14	-	-	0	30.06
0200	0	12	17	.6	1.5	2.6	278	241	379	5	180	15	-	-	0	30.05
0300	0	12	15	.6	1.1	2.6	326	281	337	4	110	13	-	-	0	30.05
0400	0	18	10	.6	1.4	2.7	492	273	226	5	110	9	-	-	0	30.05
0500	0	8	8	.6	1.5	2.8	609	265	194	5	180	9	-	-	0	30.05
0600	0	10	7	.6	1.1	3.2	462	254	322	5	180	11	-	-	0	30.08
0700	0	14	8	.6	1.2	3.1	543	292	381	7	180	11	-	-	16	30.08
0800	0	24	13	.7	1.3	3.1	509	413	306	7	190	10	-	-	87	30.10
0900	0	18	12	.6	1.5	3.0	452	282	393	8	190	24	-	-	606	30.10
1000	0	8	5	.5	1.1	2.6	244	250	161	9	170	23	-	-	456	30.10
1100	1	9	8	.4	1.0	2.4	224	209	130	7	130	25	-	-	585	30.10
1200	5	8	8	.5	1.0	2.2	276	200	252	12	160	26	-	-	761	30.10
1300	-	8	11	-	-	-	280	199	133	12	160	28	-	-	692	30.08
1400	-	8	17	-	-	-	368	350	200	11	130	25	-	-	637	30.07
1500	-	8	11	.2	1.0	1.7	234	237	145	14	140	22	-	-	721	30.06
1600	-	17	18	.2	.9	1.7	232	259	188	12	170	22	-	-	658	30.05
1700	27	18	16	.2	1.1	1.7	224	230	128	11	150	23	-	-	596	30.03
1800	25	8	12	.3	1.2	1.8	215	258	174	8	170	23	-	-	447	30.02
1900	15	9	18	.3	1.3	1.8	315	228	637	5	110	22	-	-	197	30.03
2000	5	18	26	.3	1.3	1.8	338	264	322	4	190	18	90	73	47	30.04
2100	3	24	24	.4	1.7	1.9	324	321	548	4	200	18	86	73	0	30.06
2200	0	29	21	.6	1.6	1.9	409	485	309	4	190	12	86	73	0	30.07
2300	0	29	21	.4	1.9	2.2	410	256	782	4	190	9	85	73	0	30.06
2400	0	22	18	.5	1.7	2.2	476	480	544	5	180	12	83	73	0	30.05

TABLE A12 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 12, 1976

	GAS	DATA								MET.	DATA					
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	16	17	.4	1.5	2.1	433	353	797	4	190	10	83	73	0	30.04
0200	0	9	16	.3	1.2	2.2	415	483	325	calm	calm	9	81	73	0	30.03
0300	0	4	16	.3	1.0	2.2	398	308	923	calm	calm	8	80	73	0	30.01
0400	0	24	14	.5	1.1	2.4	731	262	1653	calm	calm	7	80	73	0	30.01
0500	0	25	14	.8	1.5	2.7	852	233	1401	calm	calm	4	79	73	0	30.02
0600	0	48	14	.8	2.8	4.0	896	283	851	5	50	7	80	73	0	30.03
0700	0	113	22	1.5	4.7	3.5	2222	315	1071	4	60	9	80	72	36	30.04
0800	11	105	25	1.7	5.0	3.6	1384	365	758	3	60	12	81	73	150	30.05
0900	0	61	31	1.1	3.1	2.9	1173	1063	604	5	50	22	87	73	537	30.06
1000	8	31	49	.6	1.9	2.4	1290	893	1173	8	70	21	88	73	541	30.05
1100	33	11	45	.7	1.7	2.2	504	926	652	12	140	26	91	72	783	30.05
1200	68	6	40	.8	1.4	2.0	817	664	336	10	140	22	94	70	899	30.04
1300	-	6	29	.7	1.4	2.1	298	707	446	8	70	23	93	71	737	30.02
1400	81	6	26	.8	1.1	2.0	275	776	493	7	40	27	97	71	890	29.99
1500	87	6	26	.6	1.2	2.0	-	-	-	10	60	27	101	70	829	29.99
1600	76	6	21	.3	1.1	1.9	357	368	365	9	170	25	101	68	839	29.97
1700	62	5	36	.5	1.3	1.9	314	767	358	9	170	24	100	67	616	29.96
1800	41	6	38	.5	1.1	1.9	326	503	310	8	190	22	99	69	547	29.95
1900	35	9	34	.4	1.5	1.9	271	271	263	5	190	25	97	69	197	29.96
2000	25	4	27	.5	2.0	1.9	269	251	198	5	200	25	93	70	42	29.96
2100	5	9	35	1.0	1.6	1.9	363	226	2583	5	190	19	90	70	0	29.97
2200	0	9	34	.6	1.7	2.1	449	236	6652	calm	calm	13	89	71	0	29.98
2300	0	6	25	.4	1.3	2.0	313	268	492	4	120	12	89	72	0	29.99
2400	0	8	28	.4	1.3	2.1	425	316	702	5	170	11	89	72	0	29.98

TABLE A13 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 13, 1976

	GAS			DATA						MET.		DATA				
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	9	30	.5	1.3	2.3	655	289	757	calm	calm	10	88	72	0	29.97
0200	0	35	25	.5	1.3	2.5	583	217	2635	calm	calm	6	88	72	0	29.95
0300	0	22	21	.5	1.3	2.7	902	320	3499	4	190	4	87	72	0	29.95
0400	0	25	17	.5	1.3	3.0	813	251	5042	calm	calm	0	87	72	0	29.95
0500	0	26	16	.5	1.2	3.0	933	244	2541	calm	calm	4	86	72	0	29.97
0600	0	35	14	.7	1.5	3.0	984	234	1289	calm	calm	1	86	72	0	29.97
0700	0	89	19	1.3	3.2	3.0	756	234	2731	calm	calm	14	87	72	56	29.98
0800	0	110	26	1.4	5.8	3.5	1037	224	1074	6	200	12	90	73	172	29.99
0900	0	61	25	.8	3.5	2.8	674	333	6396	6	200	18	95	74	561	29.99
1000	5	17	17	.5	1.6	2.1	411	226	2919	7	200	28	98	73	733	29.99
1100	10	7	11	<.1	.9	1.9	295	223	273	8	190	25	101	73	910	29.99
1200	25	8	11	.2	.9	1.9	269	250	245	7	170	26	103	72	1061	29.98
1300	35	8	11	.2	1.2	1.9	308	238	1201	9	190	26	103	70	907	29.97
1400	30	7	9	.1	.9	1.9	329	407	1550	5	200	26	103	69	1162	29.96
1500	30	5	7	.1	.8	1.9	264	371	543	10	200	23	104	68	1237	29.95
1600	15	10	10	.1	.8	1.9	285	232	232	10	190	25	100	70	506	29.95
1700	5	12	9	.1	.9	1.9	217	276	445	13	200	27	101	70	802	29.94
1800	5	17	19	.2	.9	1.9	216	210	1058	11	190	31	100	69	716	29.94
1900	0	15	12	.2	.9	1.9	236	200	462	7	200	31	96	68	343	29.94
2000	0	18	13	.2	1.4	2.0	269	212	240	6	190	30	91	68	69	29.95
2100	0	32	19	.4	1.8	2.0	369	198	3454	7	190	25	86	68	0	29.96
2200	0	43	9	.8	2.0	1.9	453	200	3009	6	190	17	85	69	0	29.98
2300	0	17	14	.5	1.5	2.1	327	231	1023	6	190	14	84	70	0	29.99
2400	0	24	14	.4	1.1	2.2	326	665	470	5	150	15	84	71	0	29.98

TABLE A14 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 14, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	17	15	.4	1.0	2.2	446	209	1281	4	190	13	83	71	0	29.97
0200	0	30	14	.4	1.3	2.3	556	263	694	4	190	7	82	71	0	29.97
0300	0	15	14	.4	1.1	2.3	444	2111	749	4	110	13	82	71	0	29.96
0400	0	12	12	.4	.7	2.3	381	605	1091	5	190	11	82	72	0	29.96
0500	0	8	10	.3	.7	2.3	322	1025	316	13	240	15	81	71	0	30.02
0600	0	3	4	<.1	.5	1.9	228	222	152	10	280	18	77	67	0	30.04
0700	0	15	8	.2	1.1	1.9	313	204	167	8	320	14	82	67	8	30.03
0800	0	27	23	.2	1.4	1.9	442	207	568	7	30	16	84	67	26	30.04
0900	0	31	20	.2	1.4	1.9	309	206	150	6	40	19	86	68	123	30.03
1000	10	17	17	.3	1.4	2.3	578	198	398	6	60	20	88	69	248	30.04
1100	10	28	21	.2	1.5	2.2	553	205	403	5	60	19	92	70	500	30.05
1200	15	17	21	.4	1.5	2.1	647	211	878	5	120	22	95	71	736	30.04
1300	35	11	20	.5	1.5	2.1	400	238	283	10	190	26	100	71	833	30.03
1400	65	7	35	.6	1.5	2.1	415	643	588	10	180	23	102	72	590	30.03
1500	80	6	41	.6	1.5	2.1	441	1986	682	10	150	19	101	72	365	30.01
1600	55	7	36	.6	1.6	2.0	427	256	608	8	60	24	103	72	366	30.00
1700	40	12	47	.7	1.9	2.0	353	284	646	7	190	21	102	73	302	29.99
1800	10	21	35	.6	2.1	2.0	386	257	383	8	190	22	99	74	191	29.99
1900	0	28	20	.6	1.9	2.0	458	204	1409	7	190	26	96	74	115	30.00
2000	0	29	19	.6	2.0	2.0	367	1928	678	7	190	17	92	74	21	30.00
2100	0	34	15	.6	1.8	2.0	370	222	949	8	190	12	90	75	0	30.02
2200	0	39	20	.6	2.4	2.0	745	259	697	4	190	12	90	75	0	30.04
2300	0	45	17	.5	2.0	2.1	624	251	756	5	190	10	88	75	0	30.05
2400	0	22	14	.3	1.3	2.2	391	218	1024	6	190	15	89	75	0	30.06

TABLE A15 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 15, 1976

				GAS	DATA							MET.	DATA			
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	0	5	10	.2	.8	2.1	275	314	234	calm	calm	23	89	75	0	30.05
0200	0	4	10	.1	.6	2.1	273	369	233	5	190	16	89	74	0	30.05
0300	0	4	11	.1	.5	2.2	277	351	915	5	190	16	89	74	0	30.05
0400	0	5	12	.1	.5	2.3	224	359	864	6	190	16	88	74	0	30.04
0500	0	3	8	.1	.5	2.2	255	222	2972	4	190	25	87	74	0	30.06
0600	0	12	13	.4	1.1	2.2	262	223	10377	4	130	22	86	73	0	30.06
0700	0	50	18	.3	2.0	2.3	330	276	1418	5	180	15	86	73	0	30.06
0800	0	80	23	1.7	3.3	2.3	467	293	756	8	190	17	87	73	26	30.06
0900	0	65	25	1.5	3.3	2.3	594	453	1796	11	190	16	88	73	82	30.08
1000	0	35	23	.8	2.1	2.3	458	278	1363	12	200	18	88	73	121	30.08
1100	0	34	23	1.3	2.0	2.2	585	277	5739	8	200	23	90	74	121	30.09
1200	5	16	15	.5	1.4	2.1	339	209	2113	9	190	28	92	73	214	30.10
1300	5	16	15	.6	1.2	2.0	369	237	5396	14	200	28	93	73	283	30.10
1400	5	13	13	.4	1.1	2.0	368	218	1698	14	190	26	93	73	354	30.10
1500	15	12	9	.3	1.0	1.9	-	-	-	14	190	26	95	73	342	30.07
1600	15	13	9	.1	.9	1.9	177	182	375	11	190	27	97	73	677	30.07
1700	10	19	13	.3	1.4	1.9	205	183	907	10	190	28	95	73	819	30.06
1800	5	20	15	.4	1.7	1.9	230	176	603	10	190	27	92	73	445	30.06
1900	0	15	15	.5	1.5	1.9	226	178	2205	7	190	26	90	72	282	30.05
2000	0	19	17	.6	1.4	1.9	247	190	760	5	190	24	88	73	71	30.05
2100	0	37	18	.6	1.9	2.0	322	262	419	5	190	22	87	73	26	30.06
2200	0	20	18	.5	1.8	2.1	299	356	352	4	180	16	87	73	0	30.08
2300	0	25	17	.4	1.2	2.2	303	172	2608	5	190	16	86	73	0	30.08
2400	0	26	16	.2	1.3	2.3	288	341	582	6	190	19	86	74	0	30.10

TABLE A16 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 16, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	13	13	.1	1.1	2.2	317	241	330	5	190	20	87	74	0	30.10
0200	0	7	12	.2	.7	2.2	319	181	2220	calm	calm	23	86	74	0	30.10
0300	0	5	9	.2	.6	2.3	299	184	262	4	190	21	86	75	0	30.10
0400	0	4	9	.2	.6	2.3	238	242	4353	4	190	14	86	75	0	30.10
0500	0	5	10	.2	.6	2.4	246	1695	2091	3	190	8	85	75	0	30.11
0600	0	40	15	.5	2.1	2.5	318	1227	1341	calm	calm	5	85	75	0	30.11
0700	0	91	21	1.0	4.0	2.5	500	867	3270	calm	calm	11	86	75	35	30.12
0800	0	112	25	1.6	5.2	2.5	1002	764	1819	6	200	14	87	76	119	30.13
0900	10	59	21	.3	2.9	2.4	678	360	3954	7	200	28	90	77	287	30.13
1000	10	-	-	.5	1.5	2.0	448	311	330	8	200	-	-	-	-	30.13
1100	13	9	11	.2	.9	1.9	482	285	256	5	200	20	96	76	683	30.12
1200	20	7	12	.1	.9	1.9	1265	200	434	14	190	22	101	76	1072	30.10
1300	23	7	15	.2	1.1	1.9	231	272	2169	10	190	19	101	75	953	30.09
1400	11	41	55	.5	1.8	2.0	589	500	1397	7	190	23	92	75	280	30.09
1500	0	35	33	.4	1.8	2.1	343	3260	1448	7	200	17	88	74	57	30.08
1600	0	29	21	.4	2.0	2.2	592	184	251	6	200	21	85	73	29	30.08
1700	-	-	-	.3	2.2	2.1	460	244	194	7	200	-	-	-	-	30.06
1800	-	-	-	.9	3.1	2.1	622	224	291	5	200	-	-	-	-	30.08
1900	-	-	-	1.3	4.3	2.3	991	227	1841	calm	calm	-	-	-	-	30.08
2000	-	-	-	1.0	3.6	2.2	667	267	337	5	40	-	-	-	-	30.08
2100	-	-	-	.8	2.4	2.2	1345	272	439	5	30	-	-	-	-	30.10
2200	-	-	-	.7	2.4	2.5	2366	301	253	4	60	-	-	-	-	30.11
2300	-	-	-	.7	2.3	2.3	573	272	292	5	170	-	-	-	-	30.11
2400	-	-	-	.8	3.0	2.4	615	253	360	6	180	-	-	-	-	30.09

TABLE A17 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 17, 1976

	GAS DATA									MET. DATA						
Time hr	O_3 ppb	NO ppb	NO_2 ppb	NMTHC ppmC	CO ppm	CH_4 ppm	$CFCl_3$ ppt	CCl_4 ppt	CH_3CCl_3 ppt	WS knt	WD deg	σ_θ deg	TMP °F	DP °F	RAD mLy	BARO "Hg
0100	--	--	--	.9	2.8	2.6	776	258	477	4	180	--	--	--	--	30.07
0200	--	--	--	1.2	2.7	2.9	615	938	1039	calm		--	--	--	--	30.06
0300	--	--	--	1.3	2.5	3.1	1004	1178	821	4	80	--	--	--	--	30.06
0400	--	--	--	1.3	2.4	3.9	815	925	753	calm		--	--	--	--	30.07
0500	--	--	--	1.4	2.4	4.0	1273	1047	581	calm		--	--	--	--	30.08
0600	--	--	--	1.2	2.5	3.8	794	1668	523	calm		--	--	--	--	30.10
0700	--	--	--	1.1	2.3	3.3	677	681	514	calm		--	--	--	--	30.11
0800	--	--	--	1.2	2.3	3.8	735	453	615	calm		--	--	--	--	30.12
0900	--	--	--	1.5	2.5	4.8	697	516	591	6	210	--	--	--	--	30.10
1000	--	--	--	1.2	3.1	4.2	1100	1938	2185	8	210	--	--	--	--	30.10
1100	--	--	--	.7	1.7	2.5	322	202	420	10	220	--	--	--	--	30.10
1200	--	--	--	.2	.7	1.9	218	180	120	8	230	--	--	--	--	30.10
1300	--	--	--	.1	.7	1.9	260	194	115	8	200	--	--	--	--	30.08
1400	--	--	--	.1	.7	1.9	252	195	146	7	200	--	--	--	--	30.07
1500	--	--	--	.1	.7	1.9	222	189	138	8	210	--	--	--	--	30.05
1600	--	--	--	.1	.7	1.9	255	197	133	12	200	--	--	--	--	30.03
1700	--	--	--	.1	.7	2.0	207	198	129	12	200	--	--	--	--	30.03
1800	--	--	--	.1	.7	2.0	280	189	115	10	200	--	--	--	--	30.03
1900	--	--	--	.1	.9	2.0	328	177	138	8	200	--	--	--	--	30.03
2000	6	14	16	.1	1.1	2.0	348	185	173	7	200	28	94	70	85	30.04
2100	2	13	13	.3	1.4	2.0	377	183	178	6	180	27	91	73	0	30.07
2200	1	13	12	.2	1.3	2.0	327	199	369	5	180	23	89	73	0	30.07
2300	0	16	16	.3	1.0	2.1	252	374	326	7	200	17	88	72	0	30.05
2400	0	13	13	.3	1.0	2.1	310	212	149	7	200	23	87	72	0	30.03

TABLE AJ8 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 18, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	3	5	8	.1	.6	2.0	229	195	177	8	210	27	87	72	0	30.02
0200	2	5	10	.1	.6	2.1	217	254	149	5	220	22	86	72	0	30.02
0300	2	4	9	.2	.6	2.1	208	268	184	calm		24	84	72	0	30.02
0400	3	3	8	.3	.6	2.1	208	248	181	calm		16	83	72	0	30.04
0500	0	8	9	.2	.6	2.2	273	239	252	calm		6	82	72	0	30.07
0600	0	20	11	.2	1.0	2.3	391	227	1073	calm		9	82	72	0	30.08
0700	1	18	11	.5	1.1	2.6	410	214	1072	5	170	7	82	72	48	30.10
0800	3	19	11	.4	1.1	2.6	496	288	531	6	70	15	86	73	247	30.11
0900	7	9	11	.2	.7	2.2	251	385	541	5	190	22	89	74	351	30.12
1000	10	11	11	.3	.9	2.1	334	251	497	4	190	17	93	75	531	30.12
1100	18	6	5	.2	.8	2.0	212	183	130	5	190	21	99	75	934	30.12
1200	27	3	5	.2	.5	2.0	235	189	120	4	200	15	102	75	1040	30.11
1300	43	4	7	.2	.7	2.0	242	195	149	10	200	20	104	74	1313	30.10
1400	58	4	7	.2	.7	2.0	242	194	96	8	190	17	105	72	1174	30.08
1500	41	4	7	--	--	--	242	189	106	10	190	22	106	72	1269	30.06
1600	46	5	8	--	--	--	217	194	135	10	200	27	103	72	839	30.05
1700	54	4	8	--	--	--	223	427	323	9	190	29	102	72	793	30.05
1800	35	5	12	--	--	--	221	442	224	8	200	29	98	72	407	30.05
1900	15	8	15	--	--	--	238	279	428	6	190	25	95	71	127	30.06
2000	6	11	14	--	--	--	287	214	172	5	200	31	92	71	60	30.06
2100	1	19	17	--	--	--	304	202	183	6	200	27	89	71	0	30.07
2200	1	14	16	.2	1.1	1.8	411	470	453	5	190	24	87	70	0	30.10
2300	1	11	14	.2	1.2	1.8	406	230	287	4	170	22	85	70	0	30.10
2400	0	21	16	.2	1.1	1.8	371	553	487	4	70	10	83	71	0	30.11

TABLE A19 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 19, 1976

				GAS	DATA							MET.	DATA			
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	22	13	.3	.9	2.1	322	510	957	4	150	4	83	71	0	30.12
0200	0	32	16	.4	1.4	2.3	634	257	512	5	190	11	82	72	0	30.12
0300	0	34	14	.6	1.3	2.7	1289	233	463	8	190	5	81	71	0	30.11
0400	0	25	14	.6	1.1	2.4	1698	220	2304	calm		10	81	72	0	30.11
0500	0	23	12	.4	1.1	2.6	838	300	1646	3	180	9	81	72	0	30.12
0600	0	22	15	.6	1.7	2.5	620	191	1224	calm		9	81	72	0	30.12
0700	1	117	22	1.3	5.3	2.9	745	220	1172	5	180	13	82	72	68	30.14
0800	1	85	16	1.3	3.7	2.3	763	305	7013	5	190	18	85	74	242	30.16
0900	4	34	18	1.1	1.7	1.9	313	304	4151	6	200	26	92	74	576	30.16
1000	14	26	11	.4	.9	1.8	281	334	406	10	200	30	96	74	886	30.16
1100	22	10	10	.4	1.0	1.9	237	396	241	10	190	25	99	73	1052	30.16
1200	26	14	8	.3	.7	1.7	271	424	347	11	200	22	101	73	1162	30.16
1300	30	8	6	.1	.7	1.7	183	251	164	11	200	24	103	72	1379	30.15
1400	30	8	6	.1	.7	1.6	215	229	327	13	200	27	103	72	1125	30.14
1500	27	5	7	.2	.9	1.6	366	289	367	11	200	28	95	73	579	30.14
1600	21	11	11	.3	1.1	1.6	351	225	541	10	200	22	95	71	290	30.13
1700	16	18	15	.4	1.6	1.6	329	212	1221	10	190	23	96	72	446	30.12
1800	11	23	11	.4	1.9	1.6	250	187	589	9	200	33	97	71	586	30.11
1900	11	15	10	.4	1.3	1.6	219	222	556	7	200	30	94	71	307	30.12
2000	5	14	15	.4	1.4	1.7	247	183	1741	6	190	26	90	72	34	30.13
2100	2	19	14	.7	1.5	1.8	349	182	1832	7	190	27	87	72	0	30.14
2200	0	26	12	.6	1.6	1.8	334	224	11291	8	190	25	85	72	0	30.14
2300	0	22	10	.3	1.2	1.9	335	209	10586	6	190	23	84	72	0	30.15
2400	0	20	8	.3	1.0	2.2	436	179	2501	4	200	21	82	72	0	30.14

TABLE A20 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 20, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	16	9	.2	.8	2.2	525	184	312	4	200	15	81	72	0	30.14
0200	0	12	10	.3	.7	2.1	504	199	392	calm		13	81	72	0	30.13
0300	0	8	8	.4	.7	2.1	443	192	426	calm		11	80	72	0	30.13
0400	0	13	8	.6	.6	2.2	468	196	439	calm		3	79	71	0	30.13
0500	0	31	6	.5	1.1	2.3	608	198	820	calm		4	79	70	0	30.15
0600	0	75	6	.7	1.8	2.4	904	215	1506	calm		17	78	70	0	30.16
0700	0	140	5	1.2	4.1	3.0	1343	245	1003	calm		8	79	71	68	30.18
0800	1	103	15	1.2	5.8	3.5	721	239	1024	calm		21	84	74	334	30.19
0900	8	39	24	.6	2.9	2.1	1438	313	2318	8	190	20	92	75	656	30.19
1000	27	24	28	.6	2.1	2.2	404	278	1069	9	190	29	93	73	713	30.18
1100	--	7	13	.2	.9	1.7	340	226	809	8	180	26	97	72	1118	30.18
1200	--	6	10	.1	.9	1.8	228	207	315	10	150	29	99	71	1109	30.18
1300	--	4	10	.1	.8	1.8	233	233	251	10	150	29	100	71	1236	30.17
1400	--	6	10	.2	.8	1.8	209	231	230	10	160	29	104	72	1457	30.15
1500	62	7	11	.2	.8	1.8	315	231	182	10	170	27	103	70	1379	30.14
1600	62	7	12	.2	.9	1.8	210	251	232	10	160	32	103	70	1244	30.12
1700	58	10	16	.3	1.5	1.8	212	229	811	8	160	29	100	69	954	30.11
1800	85	11	14	.4	1.3	1.8	190	460	203	9	150	24	98	68	608	30.11
1900	48	6	15	.4	1.2	1.8	220	374	590	7	150	24	93	67	247	30.11
2000	30	8	24	.5	1.2	1.8	236	259	543	5	150	26	89	68	33	30.12
2100	20	9	25	.5	1.8	1.8	349	228	963	6	170	29	86	68	0	30.12
2200	5	11	34	.7	1.9	2.2	532	230	1223	6	180	23	84	69	0	30.13
2300	5	11	33	.6	2.1	2.6	488	231	776	5	170	18	82	70	0	30.13
2400	5	9	33	.5	1.6	2.7	595	229	1920	5	180	14	81	70	0	30.12

TABLE A21 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 21, 1976

	GAS	DATA								MET.	DATA					
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	8	5	29	.4	.8	2.1	527	246	290	calm		13	81	70	0	30.11
0200	8	5	24	.3	.7	2.1	648	245	372	3	210	2	79	70	0	30.10
0300	0	11	20	.3	.7	2.2	798	248	872	3	20	4	78	70	0	30.10
0400	0	51	20	.5	.6	2.3	790	245	1413	calm		7	78	69	0	30.11
0500	0	31	21	.6	1.1	2.3	863	274	5720	3	20	12	78	69	0	30.11
0600	0	81	24	.7	1.8	2.4	684	253	1938	calm		9	78	69	0	30.13
0700	0	143	23	1.2	4.1	3.0	912	278	1252	7	130	11	77	69	23	30.14
0800	0	122	29	1.3	5.8	3.5	1393	308	870	7	90	14	80	71	132	30.16
0900	2	85	47	.6	2.9	2.1	1204	301	1900	9	100	19	83	72	256	30.17
1000	13	27	70	.6	2.1	2.2	831	1290	1012	8	120	23	86	72	395	30.16
1100	58	13	79	.2	.9	1.7	524	404	1832	6	100	25	91	72	783	30.15
1200	80	7	35	.1	.9	1.8	322	293	1057	3	80	25	97	71	1432	30.13
1300	80	4	24	.1	.8	1.8	296	228	678	8	180	23	97	71	1069	30.12
1400	100	6	19	.2	.8	1.8	216	247	337	7	150	25	99	69	1150	30.10
1500	43	4	18	.2	.8	1.8	259	228	231	9	170	25	92	70	279	30.08
1600	35	10	22	.2	.9	1.8	292	212	347	8	160	26	92	71	497	30.05
1700	40	13	28	.4	1.4	1.8	235	316	2226	9	130	29	93	72	764	30.05
1800	45	12	28	.4	1.3	1.8	224	274	235	14	110	25	92	70	439	30.05
1900	28	13	26	.3	1.2	1.8	210	261	246	9	130	25	90	68	221	30.07
2000	28	8	34	.5	1.2	1.8	265	491	346	7	170	23	89	69	15	30.08
2100	13	15	42	.6	1.9	1.8	480	219	1274	6	180	15	81	71	0	30.08
2200	0	32	46	.7	1.9	2.2	531	347	2721	4	130	14	80	73	0	30.08
2300	0	29	41	.6	2.1	2.6	450	926	4684	4	140	11	80	72	0	30.08
2400	0	36	36	.5	1.6	2.7	1138	~	1527	4	160	6	79	71	0	30.08

TABLE A22 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 22, 1976

				GAS	DATA							MET.	DATA			
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	46	36	1.3	2.8	2.6	609	1302	625	4	140	0	78	71	0	30.08
0200	0	66	34	1.1	2.3	2.8	1044	807	1611	calm		3	78	71	0	30.08
0300	0	69	37	.9	2.0	3.0	995	650	1688	4	230	1	77	71	0	30.08
0400	0	53	31	1.1	1.9	3.2	1307	503	4153	calm		4	78	71	0	30.08
0500	0	63	30	1.0	1.7	3.1	1230	390	2819	calm		4	77	71	0	30.10
0600	0	106	37	1.3	2.5	3.2	1561	318	2242	calm		7	77	71	0	30.12
0700	0	*	*	1.9	6.4	3.4	1045	276	1639	calm		9	78	71	57	30.13
0800	0	*	*	1.7	6.1	3.5	1467	327	702	calm		14	81	73	271	30.14
0900	5	26	125	.7	2.5	2.5	560	412	2137	10	130	22	88	74	490	30.15
1000	43	12	83	.3	1.5	1.9	380	452	823	5	90	23	93	74	843	30.15
1100	25	8	49	.1	1.0	1.7	258	279	389	6	150	22	96	72	1247	30.14
1200	38	7	39	.1	.9	1.7	234	268	400	10	100	18	99	70	1293	30.14
1300	50	8	40	.2	.9	1.7	239	222	702	7	100	23	99	69	1183	30.12
1400	53	4	30	.1	.8	1.7	197	215	222	5	140	20	100	68	1159	30.11
1500	68	6	26	.1	.9	1.7	190	203	803	9	140	21	101	68	1153	30.10
1600	73	4	40	.2	1.0	1.7	297	242	937	14	120	28	100	69	1045	30.09
1700	53	9	26	.2	1.1	1.7	212	244	358	12	120	29	98	70	842	30.08
1800	35	9	47	.3	1.2	1.7	235	269	308	8	150	30	97	69	645	30.08
1900	30	11	45	.4	1.3	1.7	241	199	1206	9	150	30	93	69	282	30.08
2000	23	4	39	.4	1.2	1.7	234	217	284	8	150	27	90	69	66	30.09
2100	13	11	48	.5	1.2	1.7	287	197	609	5	150	27	86	69	0	30.10
2200	3	11	51	.3	1.3	1.7	355	198	958	4	170	29	84	70	0	30.13
2300	0	13	59	.4	1.5	1.8	371	212	5106	4	180	25	82	70	0	30.13
2400	0	19	63	.6	1.5	2.1	582	210	3660	calm		14	80	71	0	30.14

*NO_x > 200 ppb

TABLE A23 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 23, 1976

			GAS	DATA							MET.	DATA				
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	20	62	.6	1.3	2.1	707	215	4300	calm		6	79	71	0	30.13
0200	0	26	66	.6	1.4	2.1	771	192	1770	calm		2	78	71	0	30.13
0300	0	40	84	.6	1.8	2.3	891	199	2152	calm		3	77	70	0	30.12
0400	0	39	87	1.1	1.9	2.7	1039	265	2008	calm		6	77	70	0	30.13
0500	0	39	93	1.6	1.9	3.1	965	242	1433	calm		8	77	70	0	30.13
0600	0	55	124	1.5	2.8	3.6	885	259	750	calm		10	77	70	0	30.14
0700	0	*	*	1.9	5.1	3.3	768	415	767	4	360	12	77	70	65	30.16
0800	3	60	143	1.1	3.1	3.2	663	522	538	calm		13	82	72	325	30.17
0900	5	25	71	.2	2.1	2.8	495	659	443	calm		18	89	74	681	30.18
1000	18	9	58	.2	1.1	1.9	401	332	538	calm		15	91	74	681	30.18
1100	28	11	63	.3	1.4	1.8	394	289	1003	6	80	17	90	73	534	30.18
1200	60	10	40	.3	1.3	1.8	357	300	355	9	40	20	91	75	748	30.18
1300	65	11	61	.3	1.1	1.8	366	364	249	8	180	14	81	67	310	30.17
1400	48	7	39	.3	1.2	1.8	331	234	378	8	140	13	83	69	313	30.18
1500	25	6	56	.3	1.2	1.8	368	256	419	8	10	21	86	71	225	30.18
1600	30	21	104	.5	2.5	1.9	796	357	1192	10	120	17	86	72	255	30.17
1700	--	--	--	.9	2.8	1.9	575	343	369	6	140	--	--	--	--	30.15
1800	8	26	65	1.0	3.1	1.9	1405	657	889	3	180	17	86	73	209	30.13
1900	15	21	89	1.2	3.8	2.0	718	1139	1821	3	140	18	86	73	169	30.14
2000	8	28	107	2.0	4.6	2.1	923	985	1393	3	150	18	84	73	53	30.14
2100	0	52	90	1.6	5.6	2.2	1274	800	1152	4	130	7	81	73	0	30.14
2200	0	91	72	2.4	6.9	2.4	1453	694	1180	4	120	3	79	73	0	30.15
2300	0	78	51	1.2	5.3	2.6	990	533	1684	5	280	11	79	73	0	30.16
2400	0	88	38	.9	4.3	2.7	1129	484	780	calm		9	78	72	0	30.16

TABLE A24 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 24, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	0	116	26	1.6	4.2	2.7	1101	408	658	calm		7	77	71	0	30.15
0200	0	80	20	1.4	2.6	2.9	739	297	308	5	300	10	77	71	0	30.15
0300	0	75	15	1.6	2.4	3.0	740	308	321	calm		3	76	70	0	30.14
0400	0	85	13	2.1	2.6	3.0	715	298	379	calm		7	76	70	0	30.14
0500	0	76	11	2.6	2.0	3.0	978	290	374	calm		10	75	70	0	30.14
0600	0	82	14	2.9	2.5	3.0	913	279	262	5	320	11	75	70	0	30.15
0700	0	77	14	1.8	2.6	2.9	612	273	262	6	350	18	75	70	35	30.16
0800	3	63	22	1.6	2.5	2.9	468	302	245	8	320	15	77	71	205	30.17
0900	8	12	28	1.0	2.6	2.5	412	310	284	9	350	15	81	73	480	30.17
1000	13	13	25	.5	1.0	2.2	220	230	132	8	30	20	89	74	931	30.16
1100	65	7	17	.2	.9	1.9	209	269	149	10	40	23	92	74	1147	30.15
1200	55	8	7	.2	.6	1.8	231	245	101	4	50	17	95	73	1065	30.15
1300	73	3	15	.2	1.9	1.8	221	277	96	5	80	21	97	72	890	30.13
1400	75	4	16	.2	.8	1.8	387	278	137	5	90	24	98	71	1200	30.09
1500	78	2	15	.3	.8	1.8	190	257	113	5	120	16	99	70	1199	30.07
1600	88	3	12	.3	.9	1.8	226	263	129	10	240	13	99	70	748	30.05
1700	83	2	15	.4	1.1	1.8	402	271	174	9	230	17	95	71	607	30.04
1800	70	4	15	.5	1.1	1.8	260	234	364	13	330	14	89	69	152	30.06
1900	50	2	13	.3	.8	1.8	532	228	167	3	260	14	76	68	26	30.08
2000	23	5	28	.7	1.5	1.8	668	244	634	3	320	17	76	70	0	30.08
2100	8	6	37	.9	2.1	1.9	1007	272	628	calm		13	76	70	0	30.09
2200	0	14	41	1.1	2.3	1.9	857	265	548	4	230	8	76	70	0	30.08
2300	0	20	39	1.2	3.0	2.1	1981	257	858	4	120	13	76	71	0	30.08
2400	5	8	26	.5	1.3	2.0	670	225	274	calm		13	76	71	0	30.06

TABLE A25 SURFACE DATA COLLECTED AT HOUSTON, TX, ON JULY 25, 1976

	GAS DATA									MET. DATA						
Time	O_3	NO	NO_2	NMTHC	CO	CH_4	$CFCl_3$	CCl_4	CH_3CCl_3	WS	WD	σ_θ	TMP	DP	RAD	BARO
hr	ppb	ppb	ppb	ppmC	ppm	ppm	ppt	ppt	ppt	knt	deg	deg	°F	°F	mLy	"Hg
0100	5	6	20	.7	1.1	2.0	442	211	229	4	270	23	76	70	0	30.05
0200	5	5	14	.7	.9	2.1	332	219	742	3	360	19	75	70	0	30.05
0300	3	4	11	.7	.8	2.1	324	210	2434	4	340	16	74	68	0	30.05
0400	0	10	12	.8	.9	2.4	259	229	456	3	20	9	74	68	0	30.05
0500	0	8	12	.7	.9	2.3	362	228	222	4	350	13	74	68	0	30.05
0600	0	9	11	.8	.9	2.4	464	233	287	3	30	15	74	68	0	30.05
0700	0	10	8	1.0	1.2	2.8	775	228	454	calm		14	74	68	0	30.06
0800	0	18	9	1.3	1.6	3.0	352	229	1982	calm		11	73	68	0	30.08
0900	5	10	10	.7	.8	2.5	213	222	248	calm		21	78	72	431	30.08
1000	13	9	12	.5	.7	2.2	197	217	149	5	230	24	84	72	777	30.08
1100	20	7	11	.4	.6	2.1	206	219	496	3	270	18	90	73	1057	30.08
1200	38	5	11	.3	.9	1.9	278	240	129	7	200	12	94	72	1273	30.06
1300	45	4	8	.4	1.0	1.8	240	237	279	4	230	--	--	--	--	30.04
1400	43	2	8	.3	.9	1.9	280	253	358	4	200	25	96	72	944	30.03
1500	102	2	8	.5	.7	1.8	301	255	153	4	20	19	97	72	1100	30.01
1600	108	2	9	.4	.8	1.8	305	268	173	8	160	19	97	73	760	29.99
1700	140	3	14	.6	1.2	1.9	388	314	234	6	130	19	97	72	254	29.97
1800	138	3	20	.8	1.2	2.0	315	367	234	8	160	23	95	71	373	29.96
1900	103	3	24	1.0	1.7	2.0	357	354	195	8	170	29	91	71	191	29.97
2000	118	3	24	1.1	1.8	2.0	429	738	371	4	180	23	87	71	27	29.99
2100	95	3	32	1.3	2.7	2.1	558	1070	833	3	160	19	84	72	0	30.01
2200	38	4	40	1.5	3.2	2.1	768	853	591	6	150	9	82	72	0	30.05
2300	23	4	37	1.3	2.5	2.2	804	693	495	6	170	7	82	72	0	30.05
2400	18	6	24	1.3	2.1	2.2	786	634	485	3	200	10	81	72	0	30.04

APPENDIX B

Three types of aircraft flight information are contained in this section.

1) A map for each flight showing the route followed, ozone concentrations (ppb) at selected points along the route, vertical sounding locations, and bag and can sample collection points.
2) Plot of ozone concentration and temperature vs. altitude for all aircraft vertical soundings.
3) Composite plots showing changes in altitude, CN counts, relative humidity, nitric oxide, nitrogen dioxide and ozone concentration vs. time (and distance) along the flight path.

The data are arranged by flight with flights numbered consecutively beginning on July 2, 1976. All times refer to Central Daylight Time.

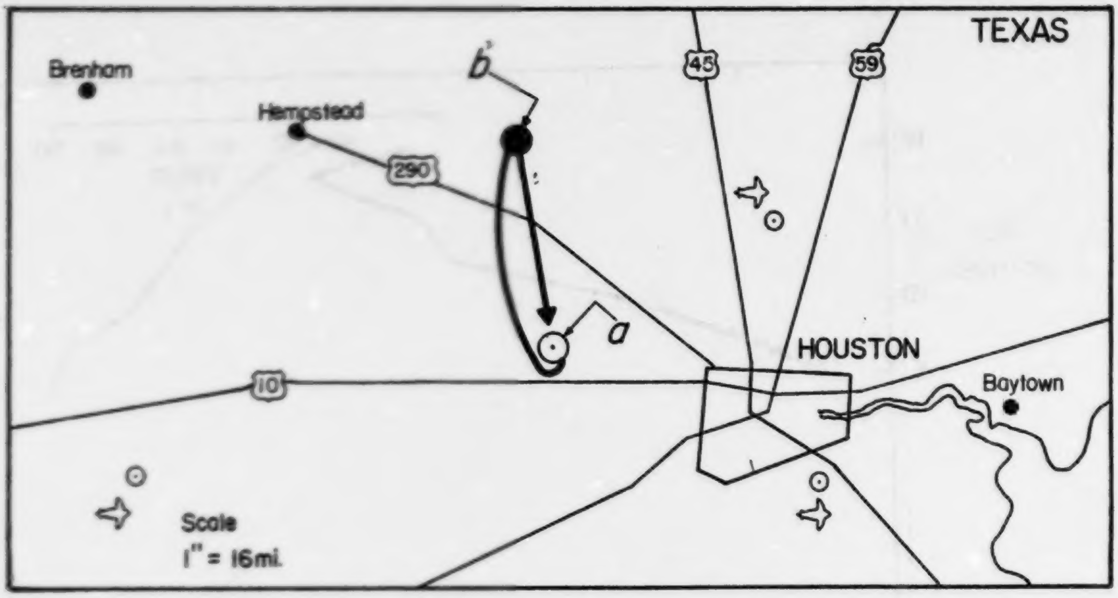

TEXAS
Brenham
Hempstead
b
45
59
290
a
HOUSTON
Baytown
10
Scale
1" = 16mi.

Figure B1. Flight #1 on July 2, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 11:20 AM to 12:20 PM

Leg ab: 11:20 - 11:26 at ~1500" MSL
b: 11:27 - 12:00 spiral ascent to 12,000' and descent to 8000'
ba: 12:01 - 12:20 slant descent to landing (inverter failure)

WIND: 150/11

WEATHER: Partly cloudy and warm

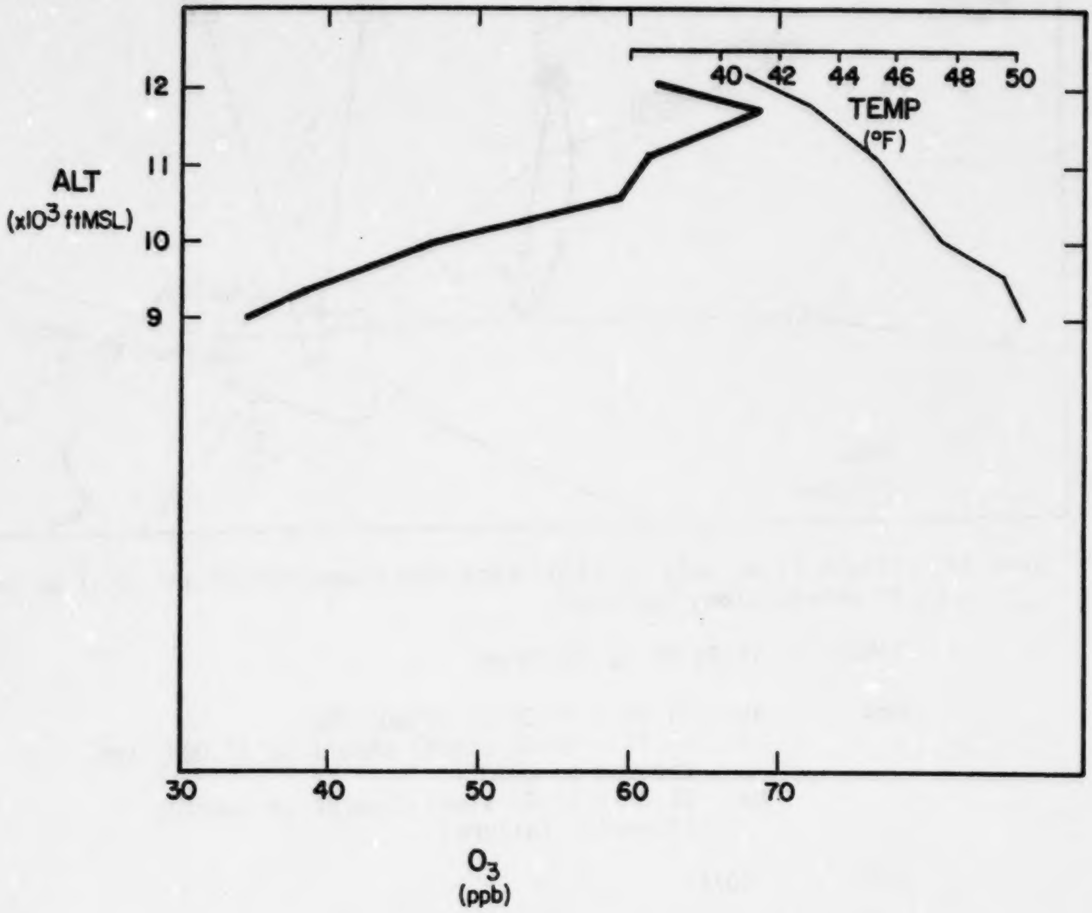


Figure B2. Vertical ozone and temperature profiles NW of Houston (flt. #1: point b) at 11:54 PM on July 2, 1976.

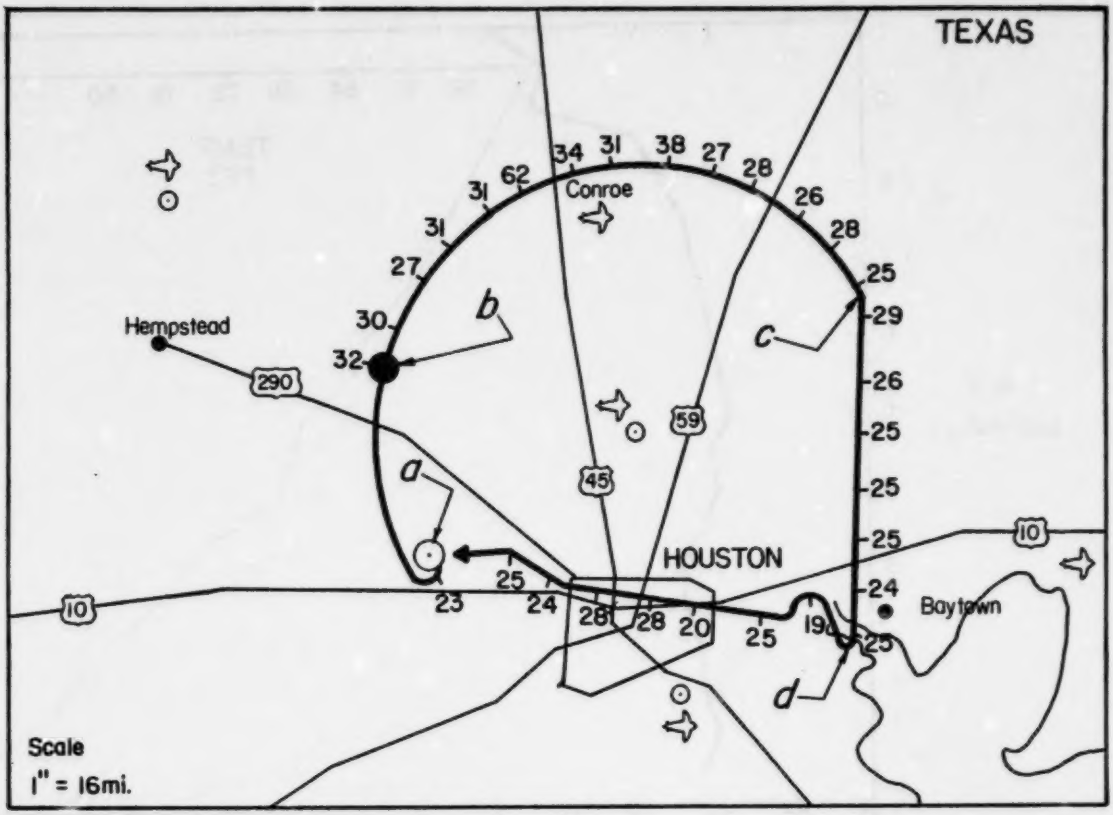

TEXAS
34
31
38
27
28
62
31
Conroe
26
31
28
27
25
b
30
Hempstead
c
29
32
290
26
59
25
a
45
25
HOUSTON
25
10
24
25
Baytown
10
23
24
28
28
20
25
19
25
d
Scale
1" = 16mi.

Figure B3. Flight #2 on July 2, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 6:00 to 7:50 PM

Leg ab: 6:00 - 6:12 at ∿1500' MSL
b: 6:13 - 6:42 spiral ascent to 12,000' and descent to 300'
bc: 6:43 - 7:11 at ∿1500'
cd: 7:12 - 7:29 at ∿1500'
da: 7:30 - 7:50 slant descent to landing

WIND: 150/10 to 18

WEATHER: Partly cloudy, 88°F

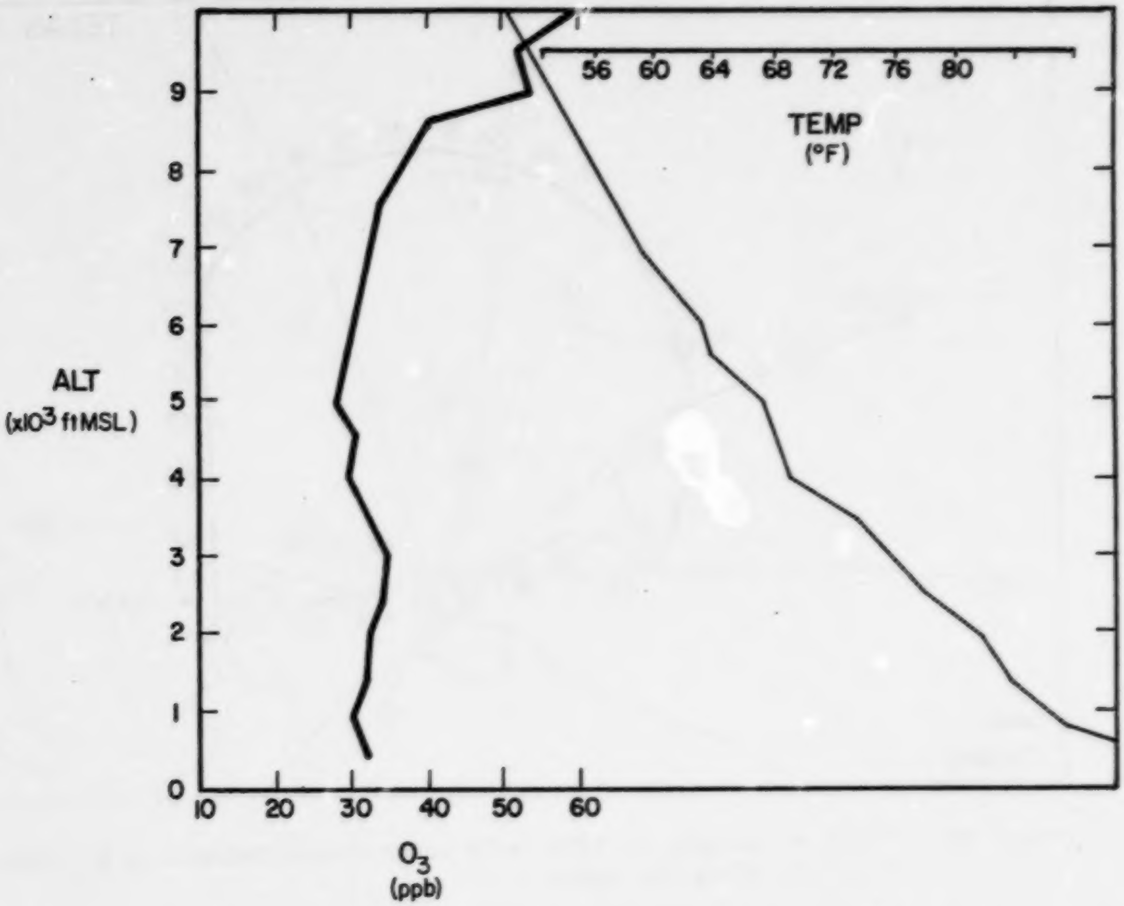


Figure B4. Vertical ozone and temperature profiles NW of Houston (flt. #2: point b) at 6:20 PM on July 2, 1976.

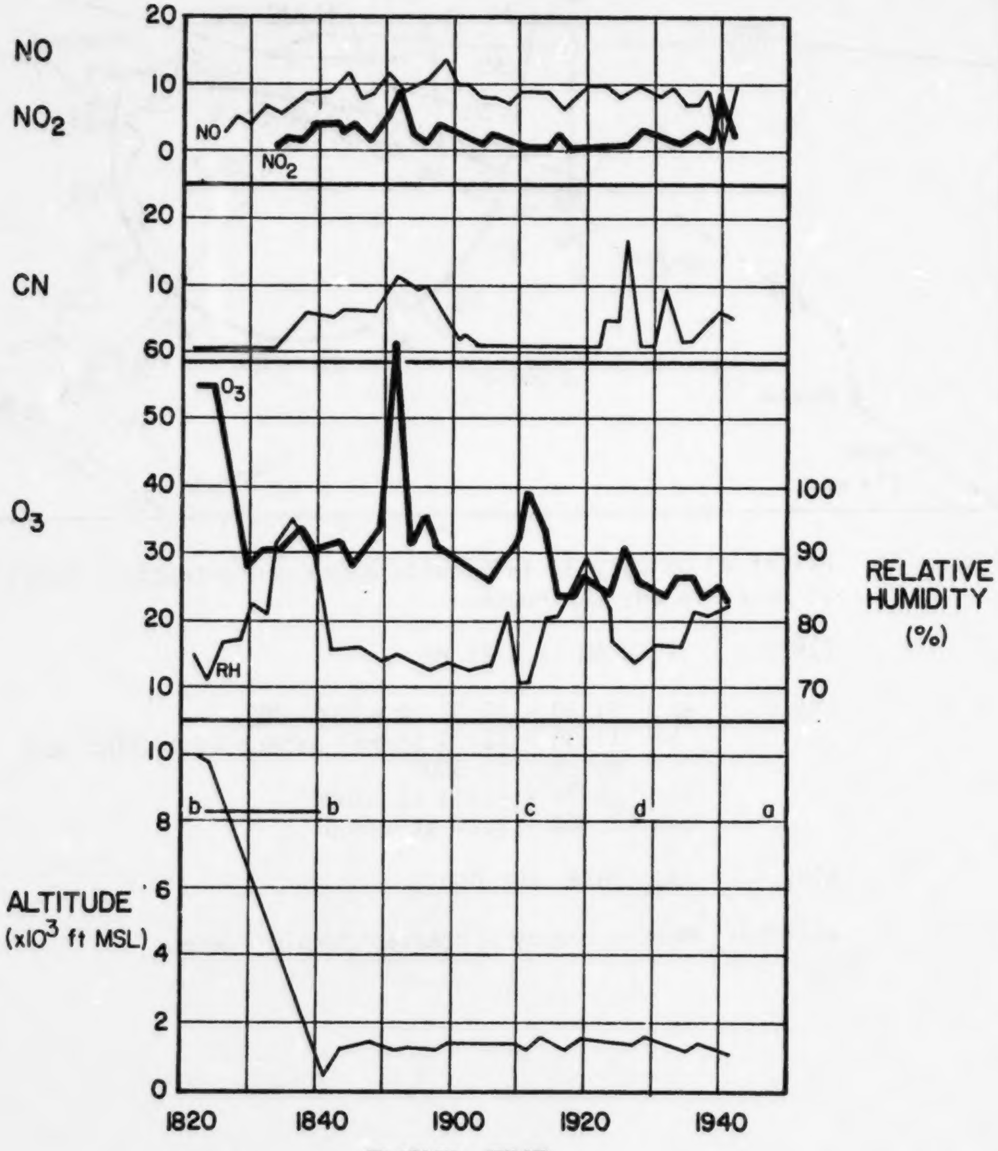


Figure B5. Plot of aircraft data recorded during flight #2 on July 2, 1976.

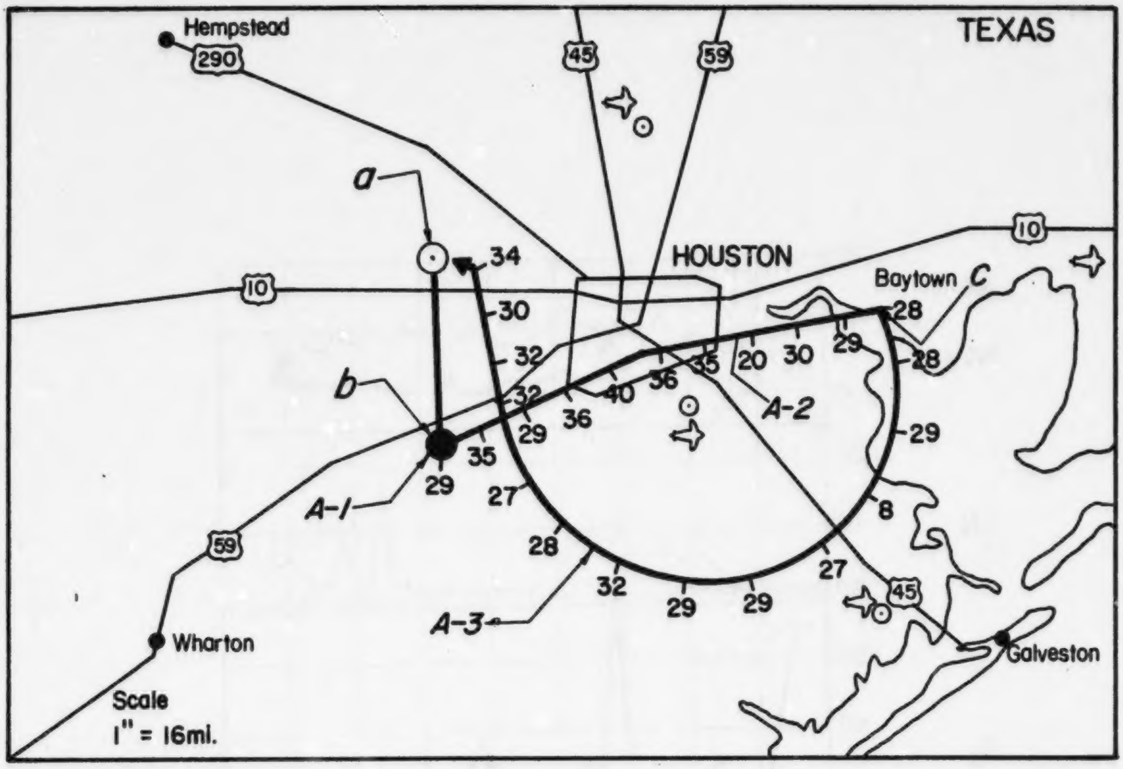

Hempstead
290
45
59
TEXAS
a
34
HOUSTON
10
10
Baytown
C
30
28
32
b
32
35
20
30
29
28
40
36
A-2
36
29
29
35
A-1
29
27
8
59
28
32
29
29
27
45
A-3
Wharton
Galveston
Scale
1" = 16mi.

Figure B6. Flight #3 on July 4, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 11:30 AM to 1:25 PM

Leg	ab:	11:30 - 11:37 at ~1500' MSL
	b:	11:38 - 12:23 spiral ascent to 11,000' and descent to 500'
	bc:	12:24 - 12:43 at ~1000'
	ca:	12:44 - 1:24 at ~1000'

WIND: IAH,190/6 HUB,050/6

WEATHER: Mostly cloudy - scattered rain - warm

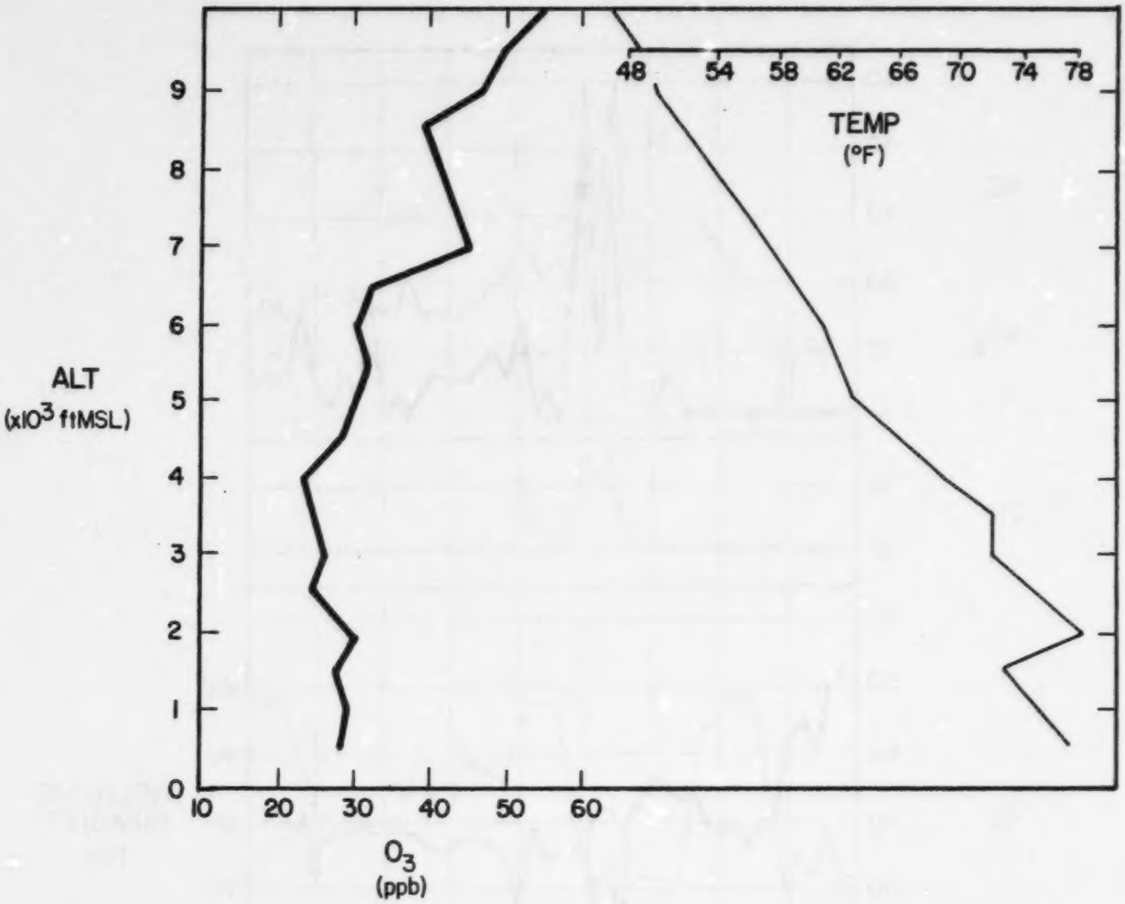


Figure B7 Vertical ozone and temperature profiles SW of Houston (flt. #3: point b) at 12:10 PM on July 4, 1976.

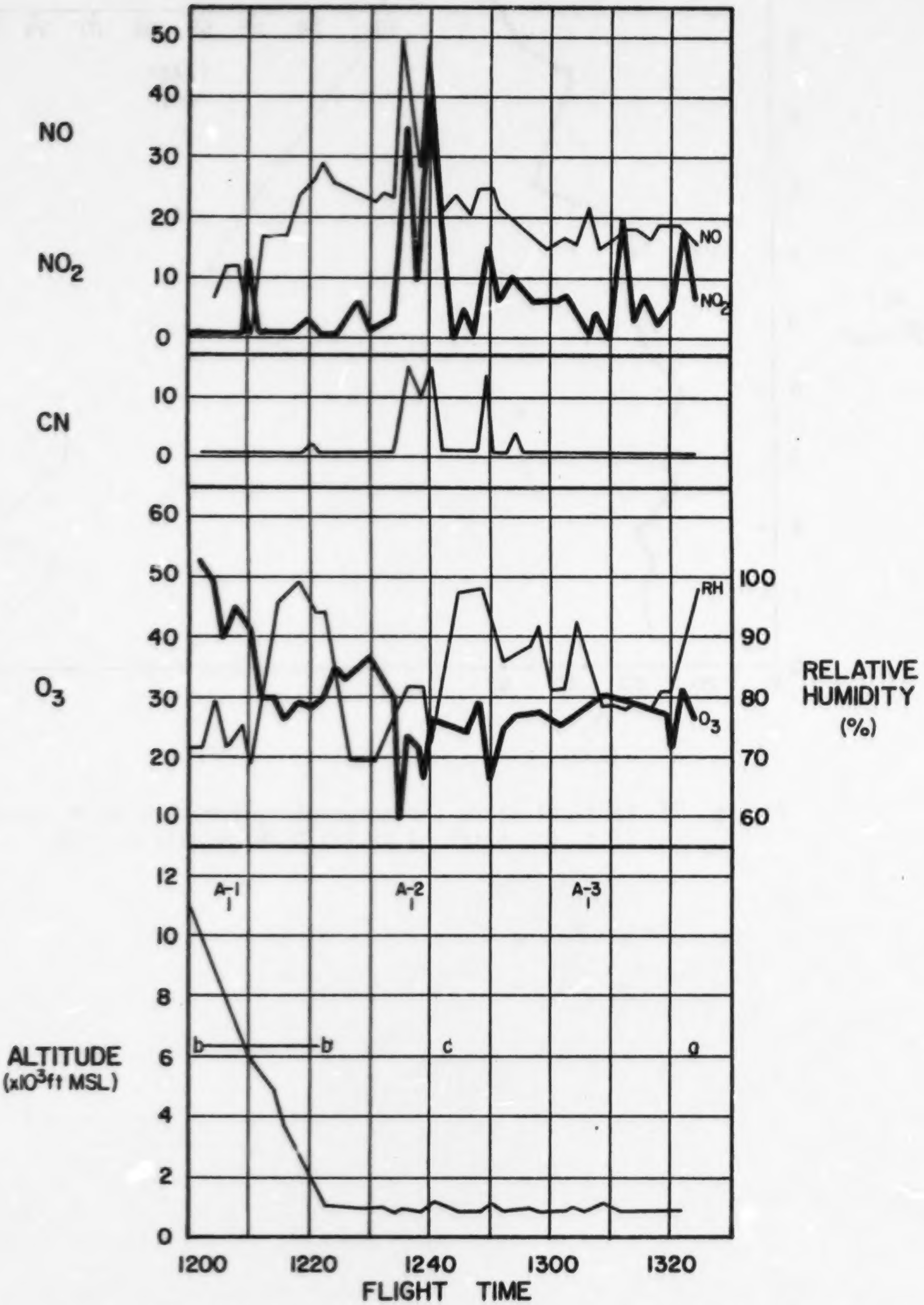


Figure B8. Plot of aircraft data recorded during flight #3 on July 4, 1976.

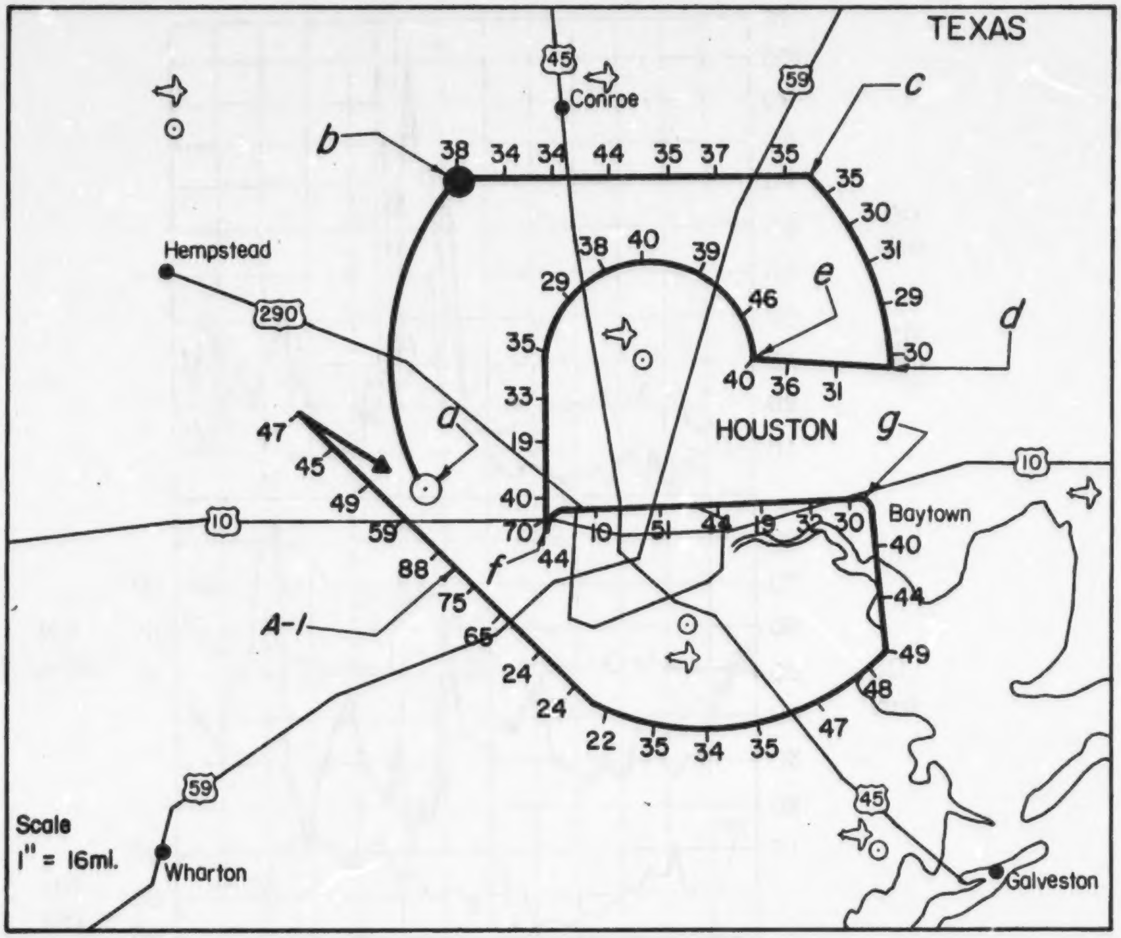

TEXAS
45
Conroe
59
c
b
38 34 34 44 35 37 35
35
30
31
29
30
d
Hempstead
290
38 40 39
29
46
e
35
33
19
40
70
40 36 31
HOUSTON
g
10
a
47
45
49
59
88
75
65
A-1
f
44
10 51 44 19 32 30
Baytown
40
44
49
48
47
24
24
22 35 34 35
59
45
Scale
1" = 16mi.
Wharton
Galveston

Figure B9. Flight #4 on July 5, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 5:40 to 8:15 PM

Leg
ab: 5:40 - 6:02 slant climb to 10,000' MSL
b: 6:03 - 6:20 spiral descent to 200'
bc: 6:21 - 6:37 at ~800'
cd: 6:38 - 6:43 at ~900'
de: 6:44 - 6:49 at ~900'
ef: 6:50 - 7:11 at ~900'
fg: 7:12 - 7:24 at ~1000'
ga: 7:25 - 8:10 at ~900'

WIND: IAH,120/7 HUB,040/7

WEATHER: High broken to overcast clouds, 77°F

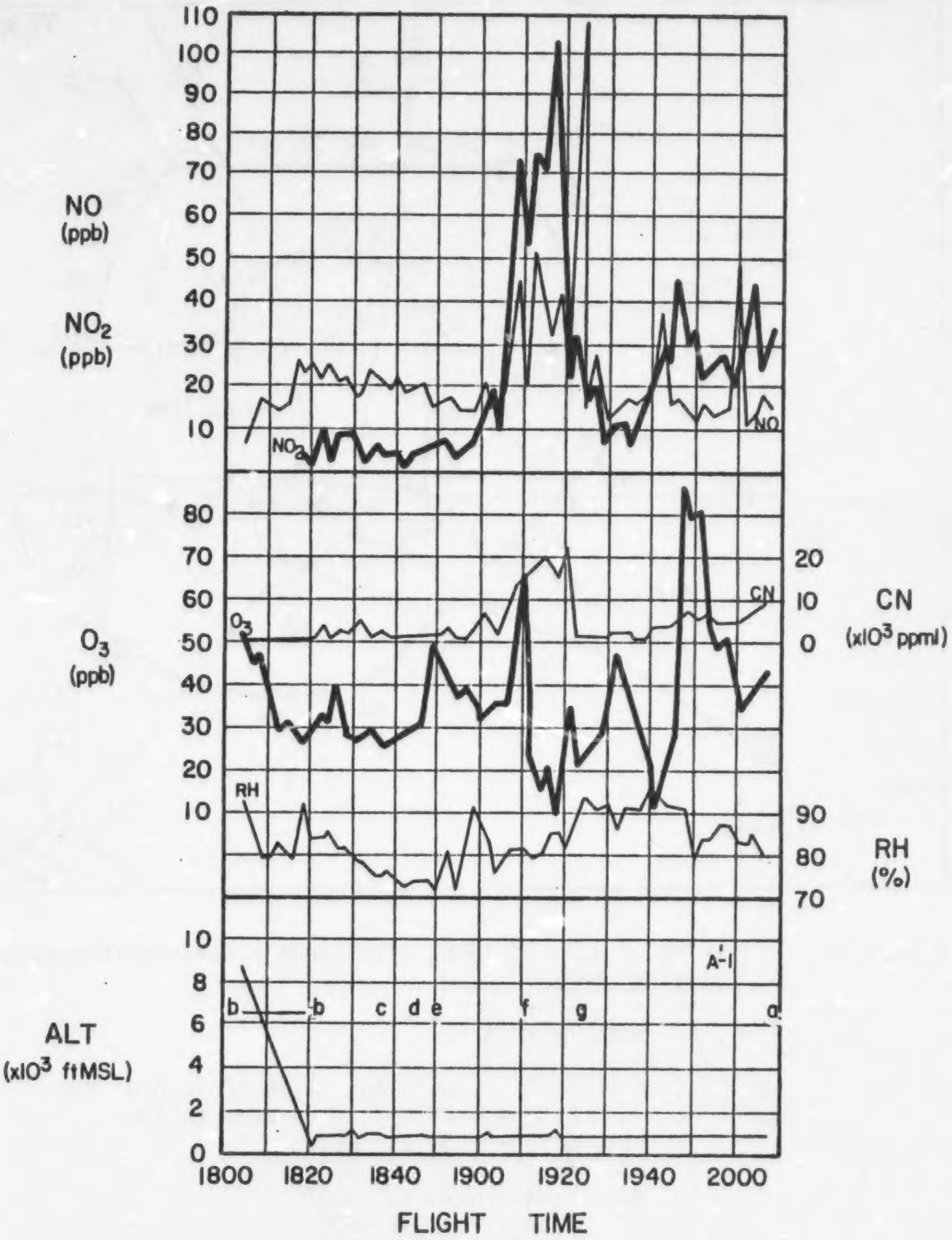


Figure B11. Plot of aircraft data recorded during Flight #4 on July 5, 1976.

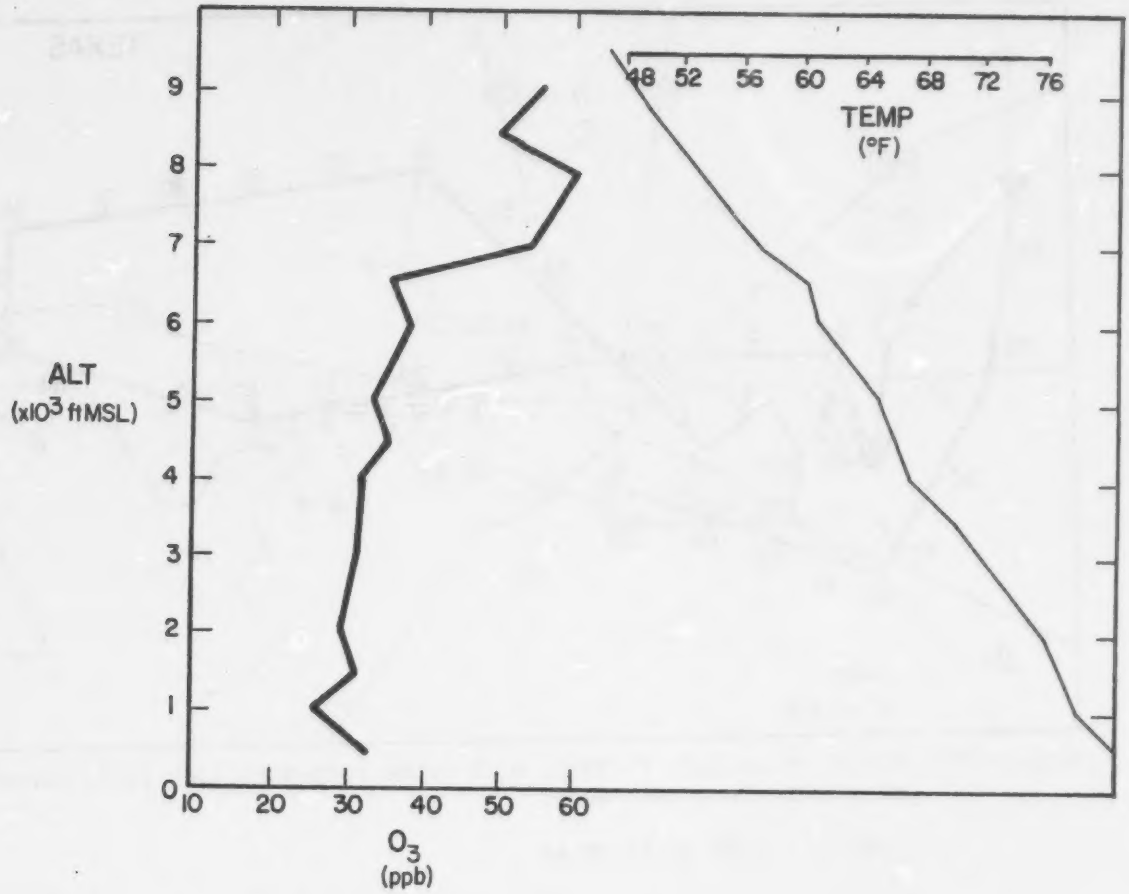


Figure B10 Vertical ozone and temperature profiles NW of Houston (flt. #4: point b) at 6:05 PM on July 5, 1976.

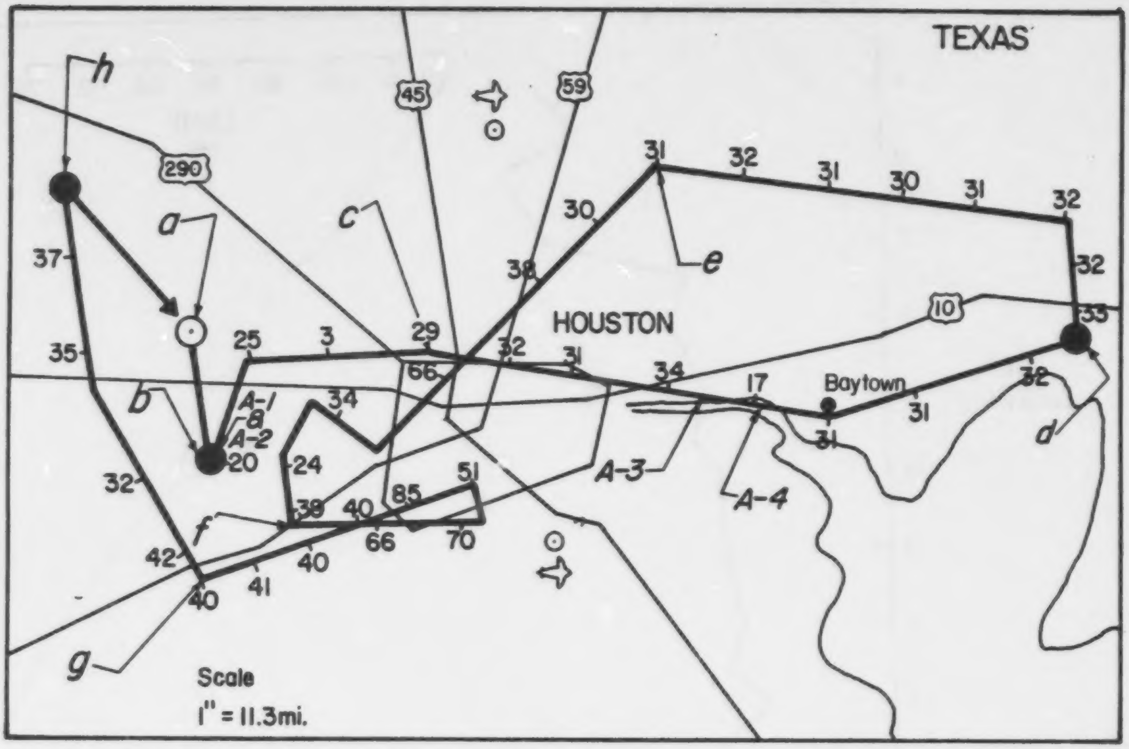

TEXAS
h
45
59
290
31
32
31
30
31
32
a
c
30
37
e
38
32
10
33
HOUSTON
35
25
3
29
32
31
34
17
Baytown
32
66
A-1
8
A-2
b
34
31
31
d
20
24
51
A-3
A-4
32
39
40
85
f
66
70
42
40
40
41
g
Scale
1" = 11.3mi.

Figure B12 Flight #5 on July 7, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 7:40 to 10:40 AM

Leg
ab: 7:40 - 8:04 slant climb to 10,000' MSL
b: 8:05 - 8:25 spiral descent to 100'
bc: 8:26 - 8:39 at ~900'
cd: 8:40 - 9:02 slant climb to 2000' and slant descent to cruise at ~900'
d: 9:03 - 9:14 spiral ascent to 4000' and descent to 1000'
de: 9:15 - 9:26 between 900' and 1300'
ef: 9:27 - 9:49 at ~900'
fg: 9:50 - 10:06 at ~1000'
gh: 10:07 - 10:19 at ~900'
h: 10:20 - 10:26 spiral ascent to 3000' and descent to 1000'
ha: 10:27 - 10:33 at ~800'

WIND: IAH,040/7 HUB,040/5

WEATHER: Partly cloudy - ground fog on eastern parts of flight - 70°F

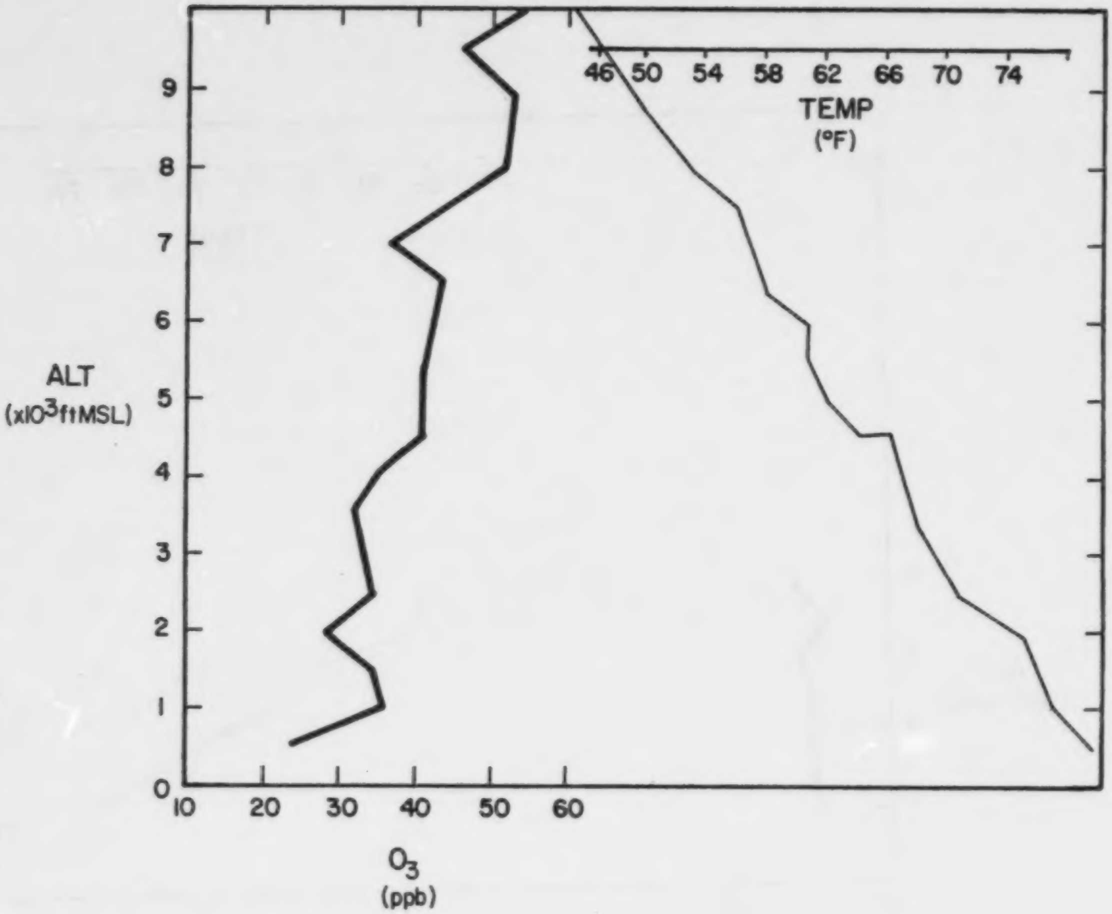


Figure B13 Vertical ozone and temperature profiles W of Houston (flt. #5: point b) at 8:15 AM on July 7, 1976.

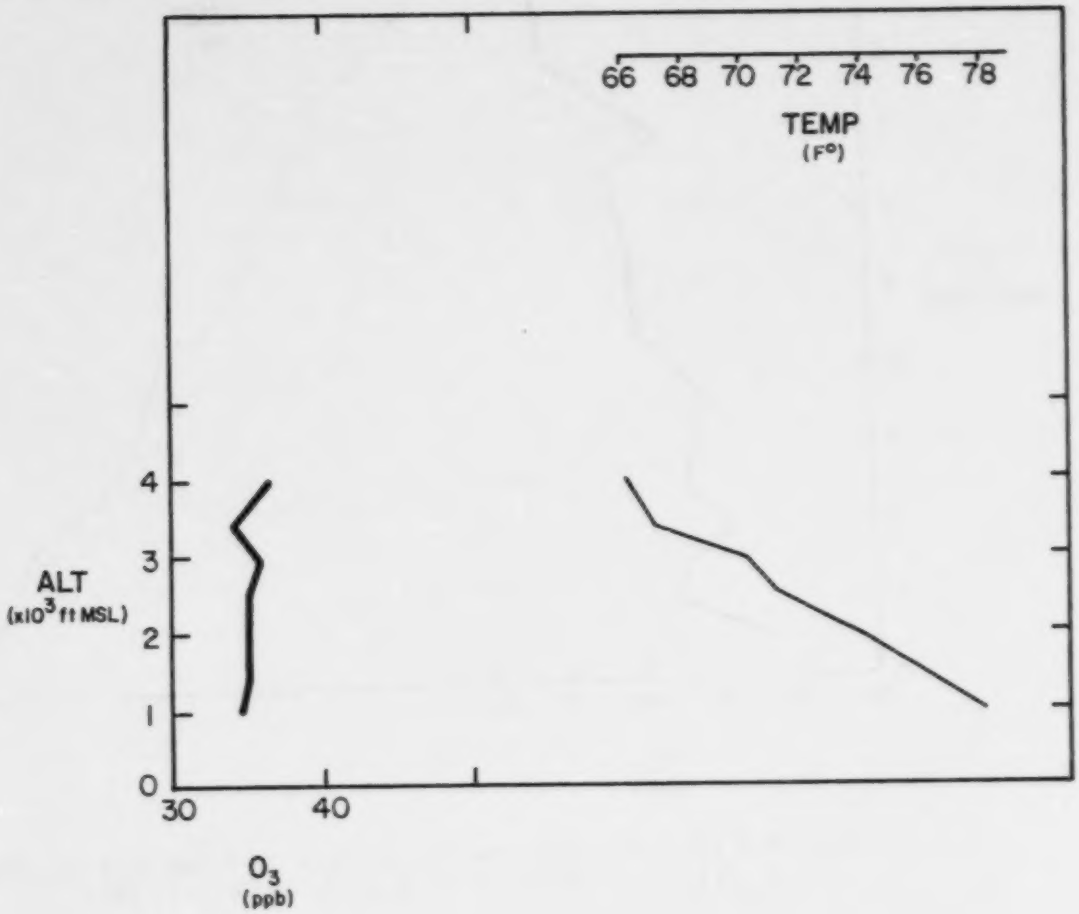


Figure B14. Vertical ozone and temperature profiles East of Houston (Flight #5: point d) at 9:09 am on July 7, 1976.

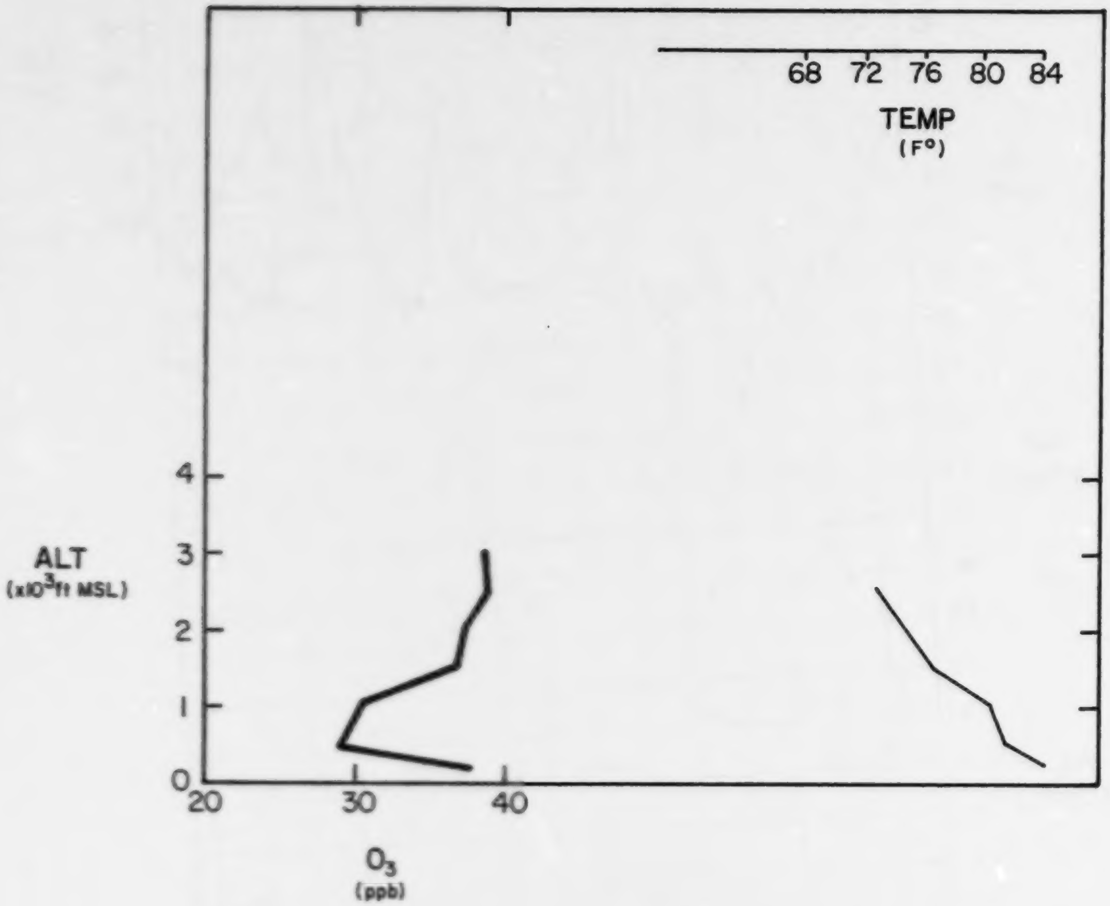


Figure B15. Vertical ozone and temperature profiles NW of Houston (Flight #5: point h) at 10:23 am on July 7, 1976.

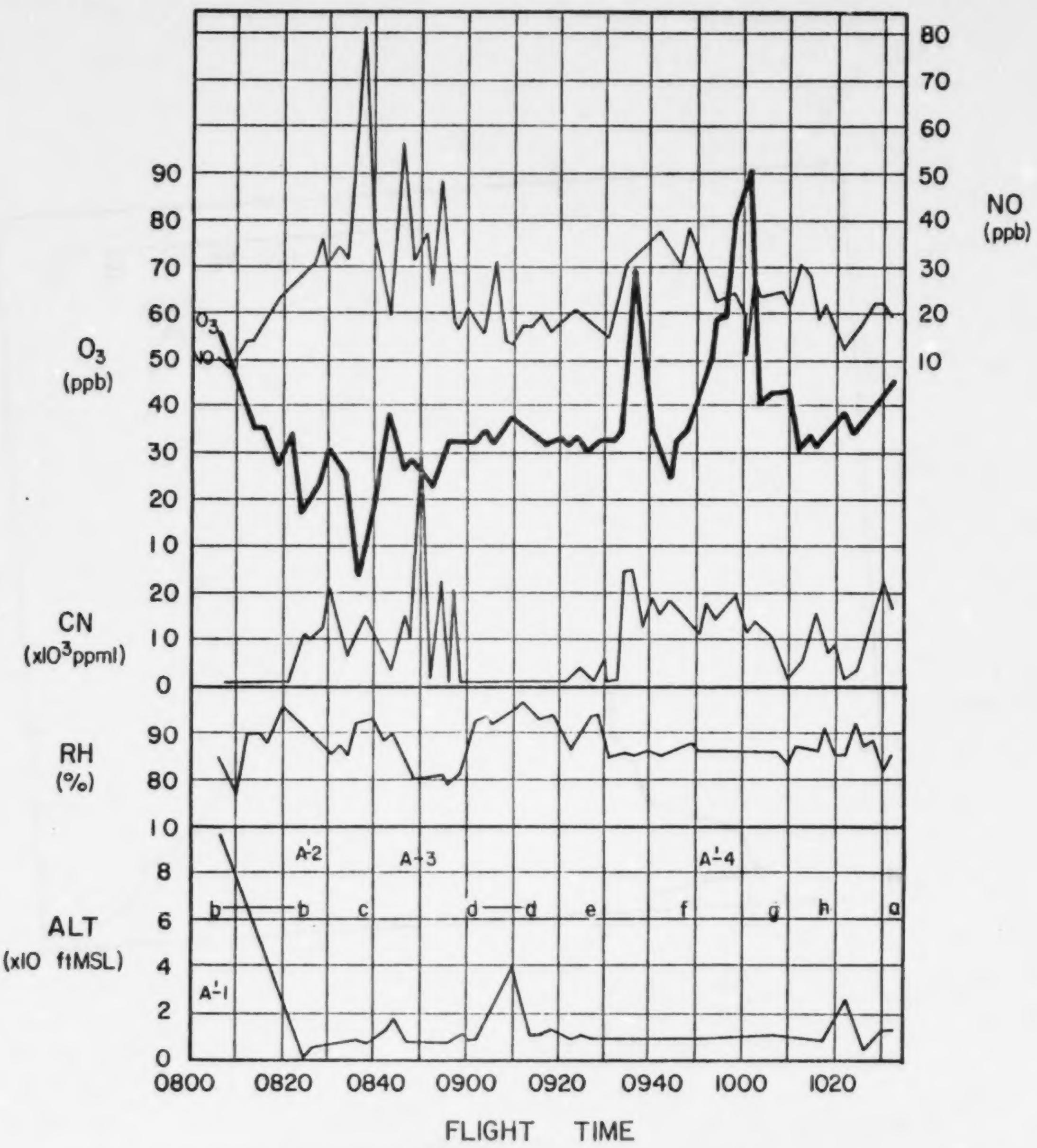


Figure B 16. Plot of aircraft data recorded during Flight #5 on July 7, 1976.

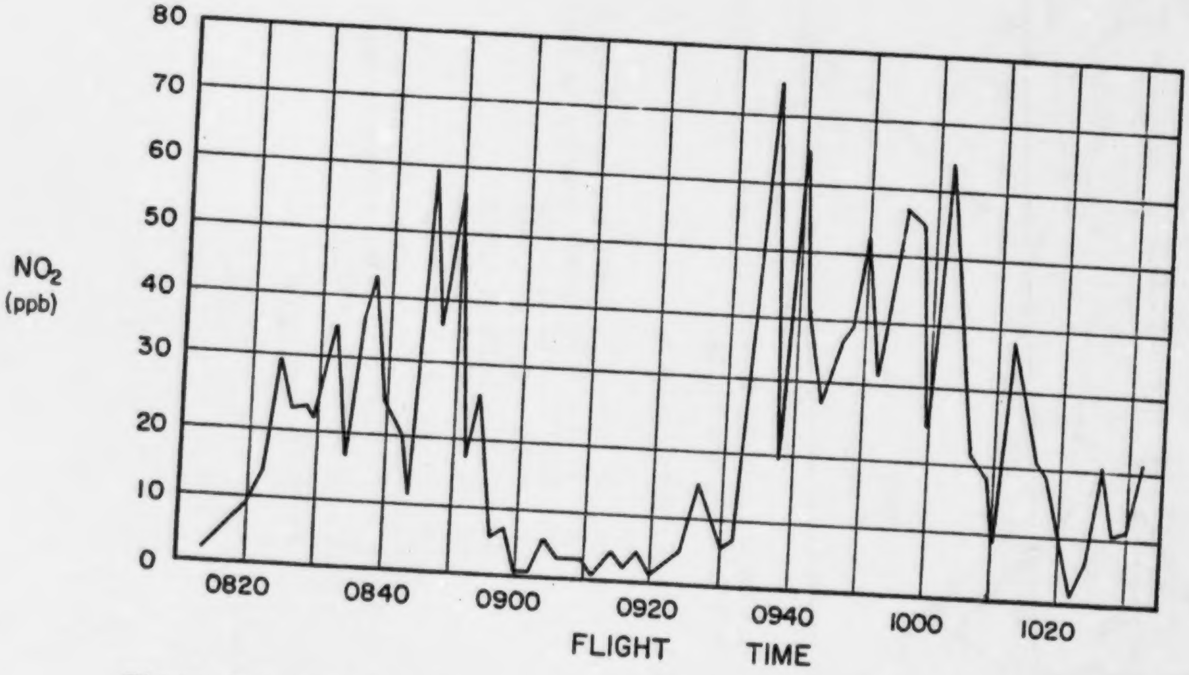


Figure B16. Continued

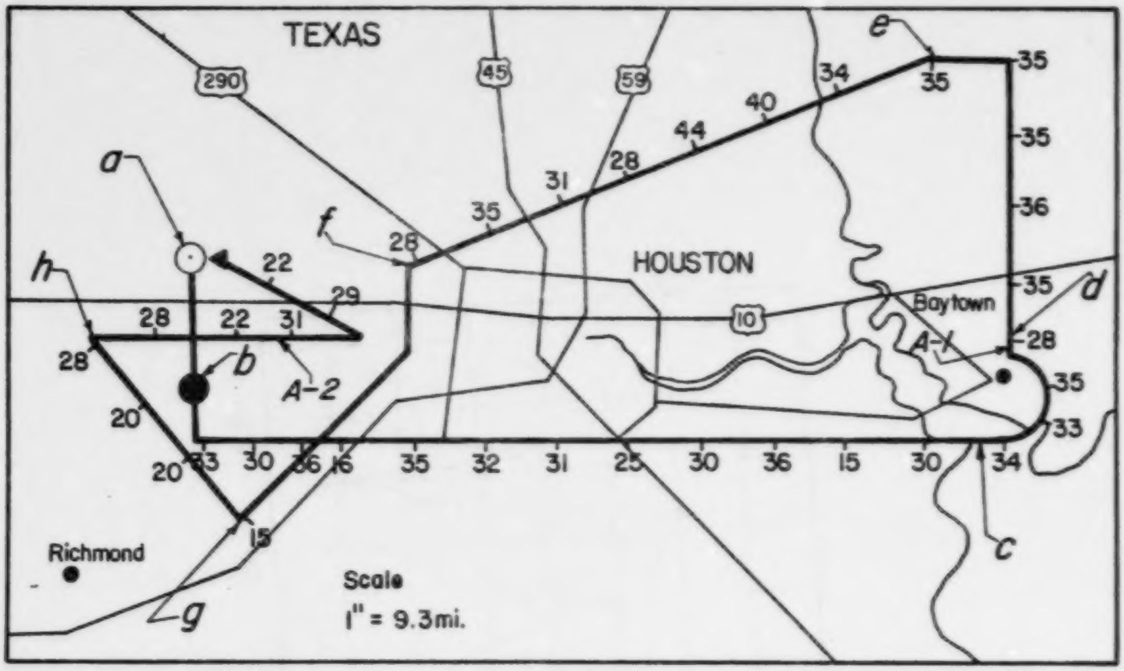

TEXAS
290
45
59
e
35
35
35
36
34
40
44
28
31
35
a
f
28
22
29
h
28
22
31
HOUSTON
10
Baytown
35
d
28
A-1
35
28
b
A-2
20
20
33
30
36
16
35
32
31
25
30
36
15
30
34
33
15
c
Richmond
g
Scale
1" = 9.3mi.

Figure B17 Flight #6 on July 8, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 8:10 to 10:10 AM

Leg
ab: 8:10 - 8:29 slant and spiral climb to 9000'
b: 8:30 - 8:50 spiral descent to 100'
bc: 8:51 - 9:14 at ~1000'
cd: 9:15 - 9:19 at ~3000'
de: 9:20 - 9:25 at ~2500'
ef: 9:26 - 9:43 at ~2500'
fg: 9:44 - 9:53 at ~1000'
gh: 9:54 - 9:59 between 400' and 800'
ha: 10:00 - 10:10 slant ascent to 3000' and slant descent to landing.

WIND: IAH,350/4 HUB,030/6

WEATHER: Clear, 71°F

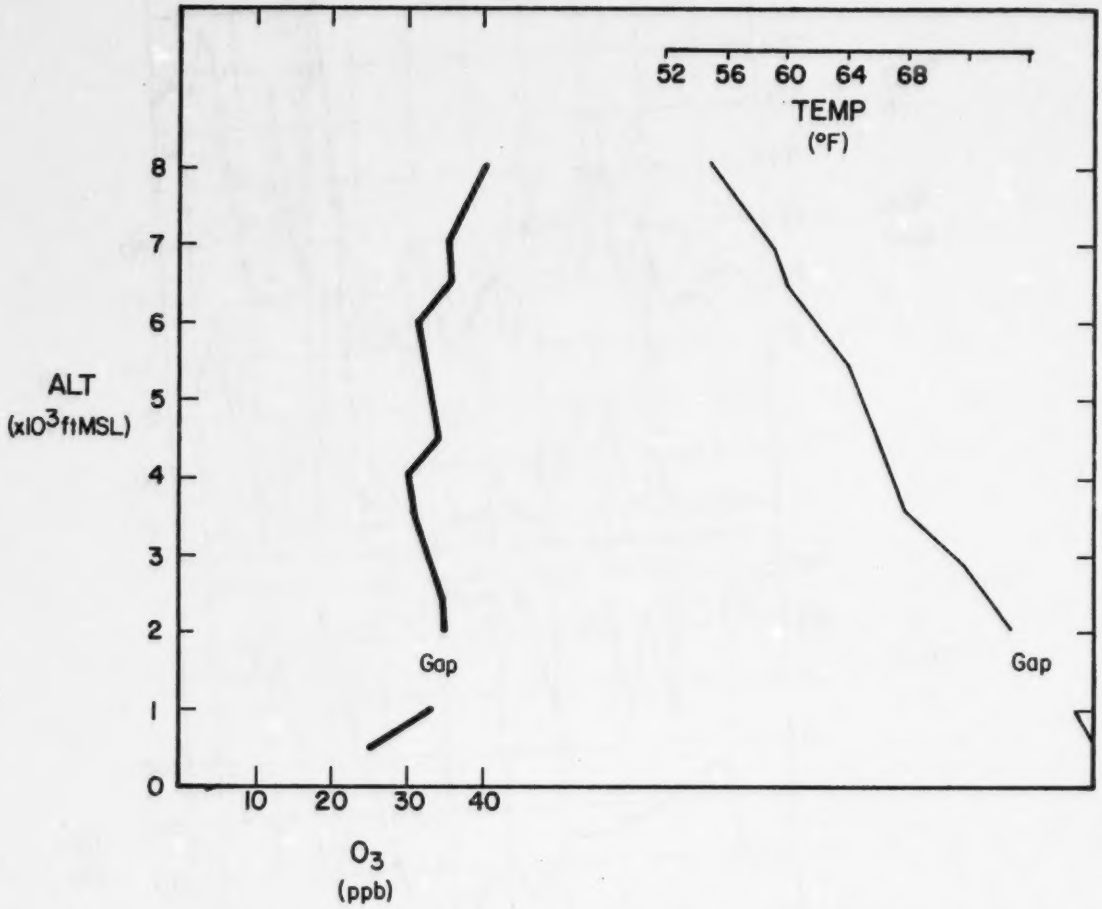


Figure B 18 Vertical ozone and temperature profiles W of Houston (flt. #6: point b) at 8:40 AM on July 8, 1976.

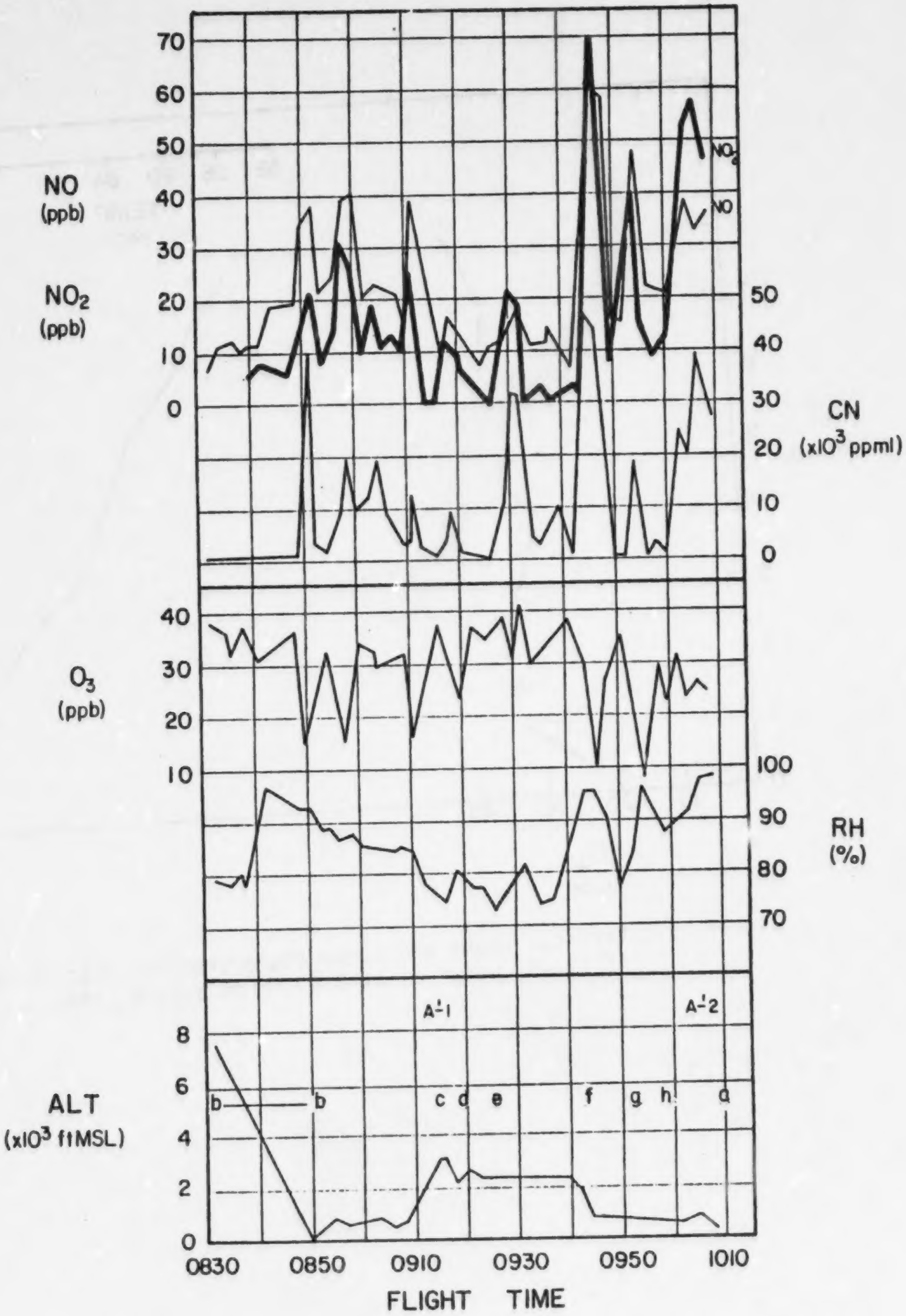


Figure B 19 Plot of aircraft data recorded during Flight #6 on July 8, 1976.

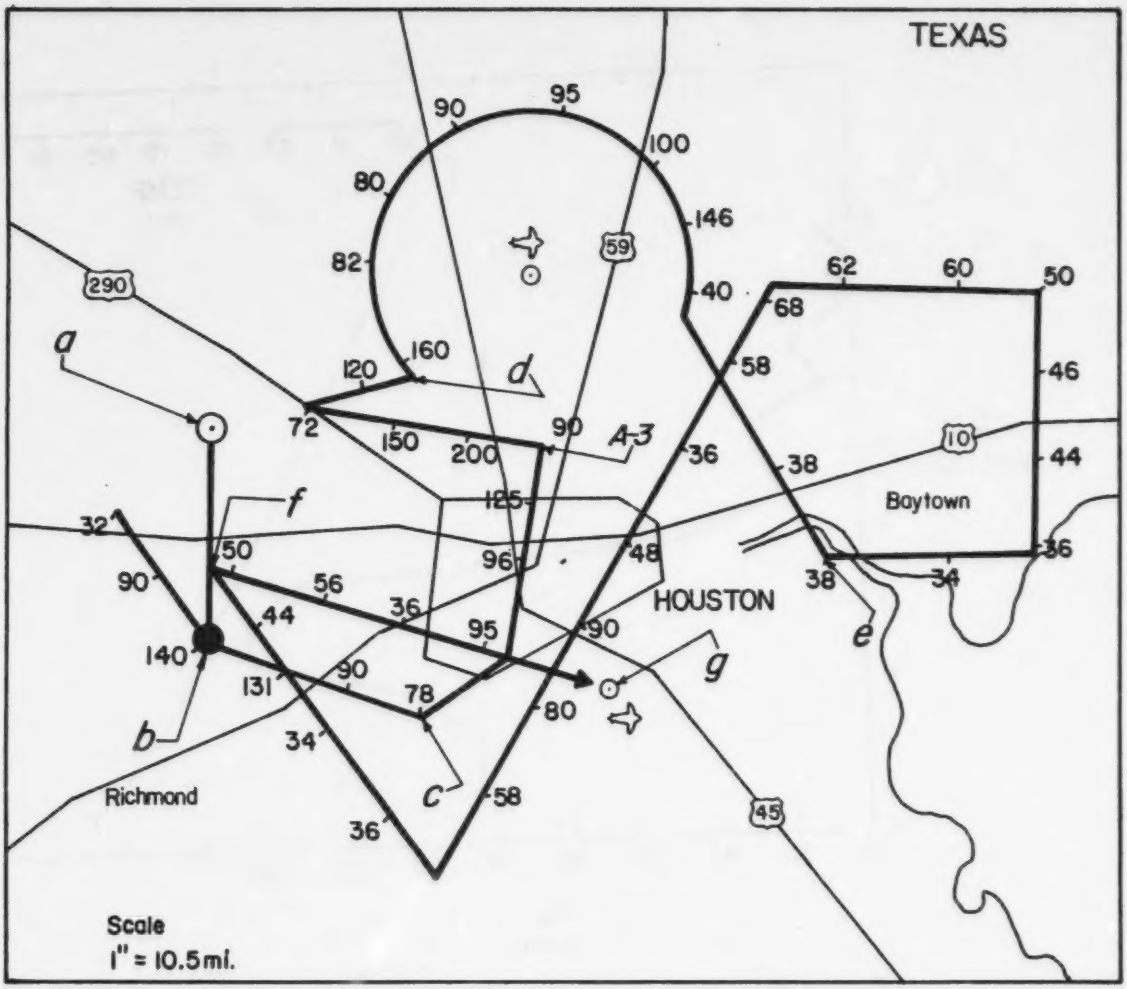

TEXAS
290
59
10
45
a
b
c
d
e
f
g
A-3
HOUSTON
Baytown
Richmond
90
95
100
80
146
82
40
68
62
60
50
160
120
72
58
46
150
200
90
36
38
44
32
125
50
56
96
48
38
34
36
90
44
36
95
90
140
131
90
78
80
34
58
36
Scale
1" = 10.5 mi.

Figure B 20 Flight #7 on July 8, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 2:50 to 5:50 PM

Leg
ab: 2:50 - 3:04 slant climb to 8000' MSL
b: 3:05 - 3:29 spiral descent to 400' and spiral ascent to 3000'
bc: 3:30 - 3:45 between 2500' and 3000'
cd: 3:46 - 4:04 at ~1000'
de: 4:05 - 4:28 at ~1200'
ef: 4:29 - 5:08 at ~1200'
fg: 5:09 - 5:50 slant climb to 2000' and descend to landing

WIND: HUB,080/4

WEATHER: Overcast - isolated thunderstorms - landing was made at Hobby due to poor visibility and rain at Lakeside

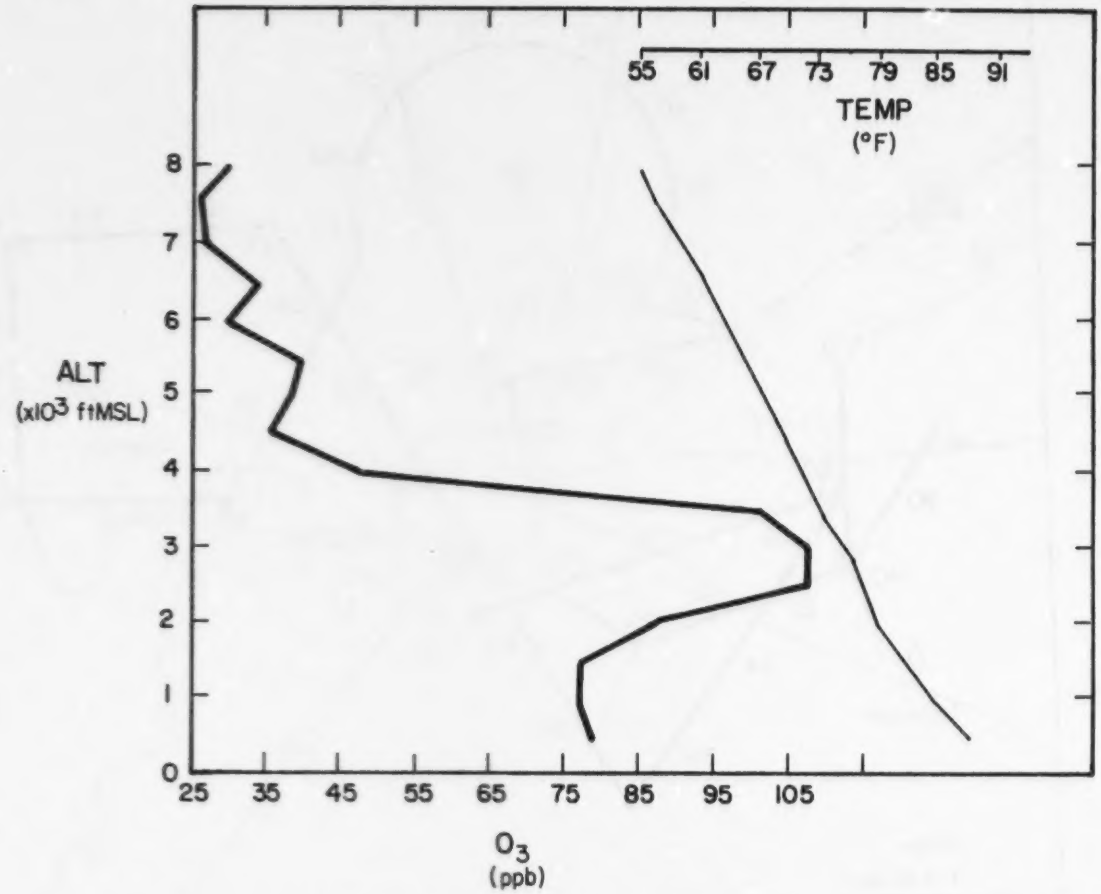


Figure B21 Vertical ozone and temperature profiles SW of Houston (flt. #7: point b) at 3:10 PM on July 8, 1976.

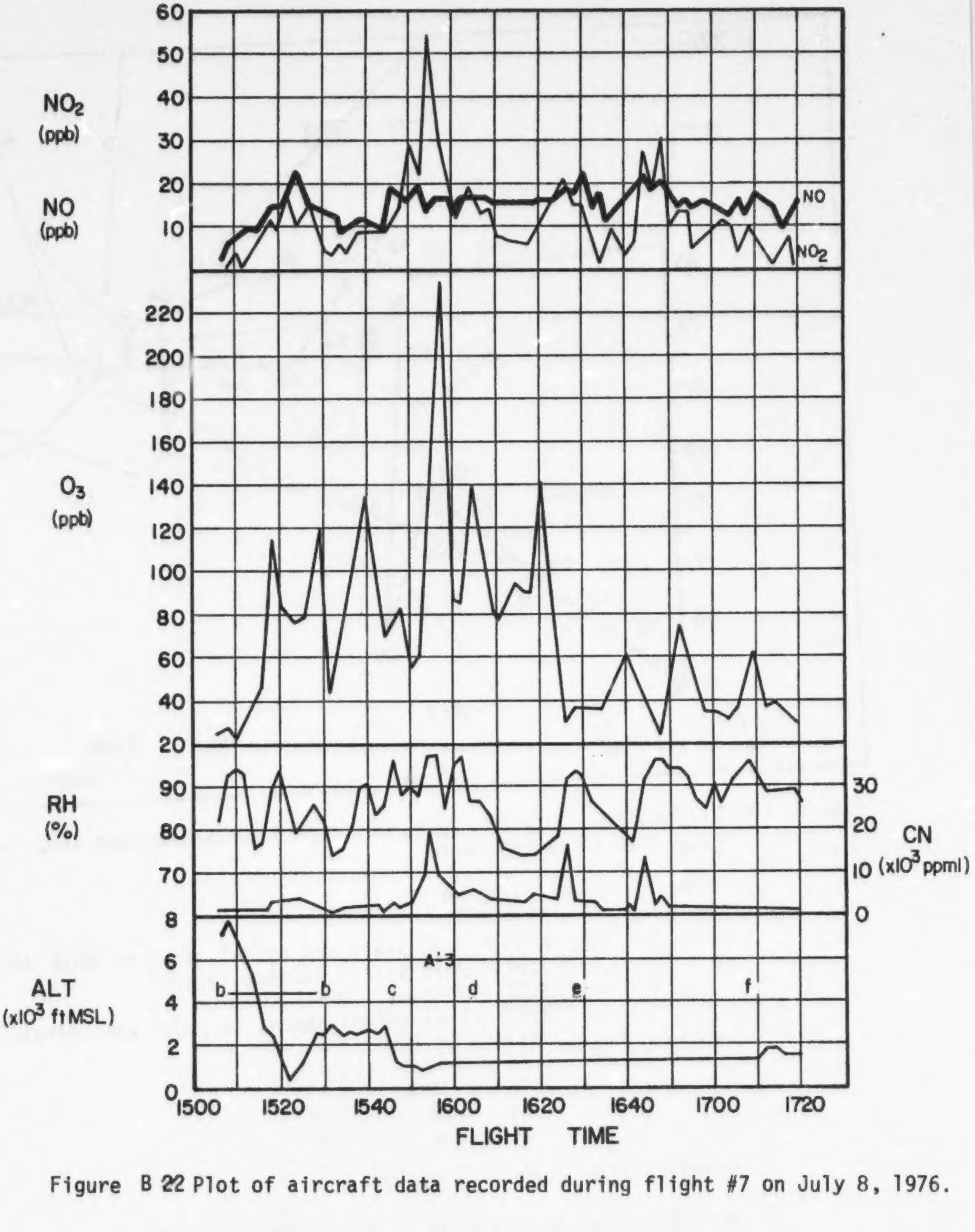


Figure B 22 Plot of aircraft data recorded during flight #7 on July 8, 1976.

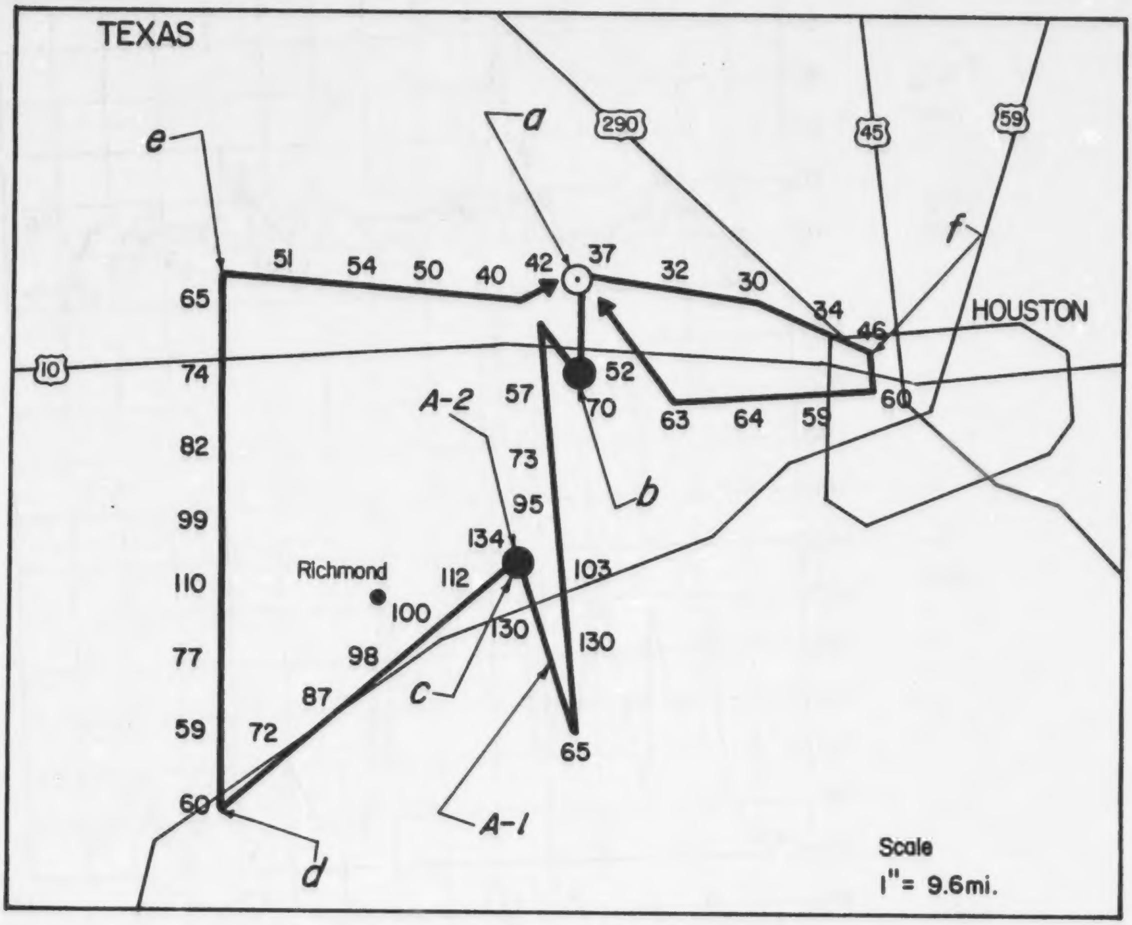

TEXAS
290
45
59
a
e
f
51
54
50
40
42
37
32
30
34
46
HOUSTON
65
10
74
52
A-2
57
70
63
64
59
60
82
73
b
99
95
134
Richmond
112
103
110
100
130
77
98
130
c
87
59
72
65
A-1
60
d
Scale
1"= 9.6mi.

Figure B23 Flight #8 on July 10, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 2:45 - 4:30 PM

Leg
ab: 2:45 - 3:00 slant and spiral climb to 9000' MSL
b: 3:01 - 3:16 spiral descent to 200'
bc: 3:17 - 3:35 at 1000'
c: 3:36 - 3:43 spiral ascent to 2500' and spiral descent to 1000'
cd: 3:44 - 3:51 at ~1000'
de: 3:52 - 4:02 at ~1000'
ef: 4:03 - 4:21 at ~1000'
fa: 4:22 - 4:30 at ~1000'

WIND: IAH,050/2 HUB,050/7

WEATHER: Overcast at 8000' - 4 to 5 miles visibility in haze and smoke - 70°F

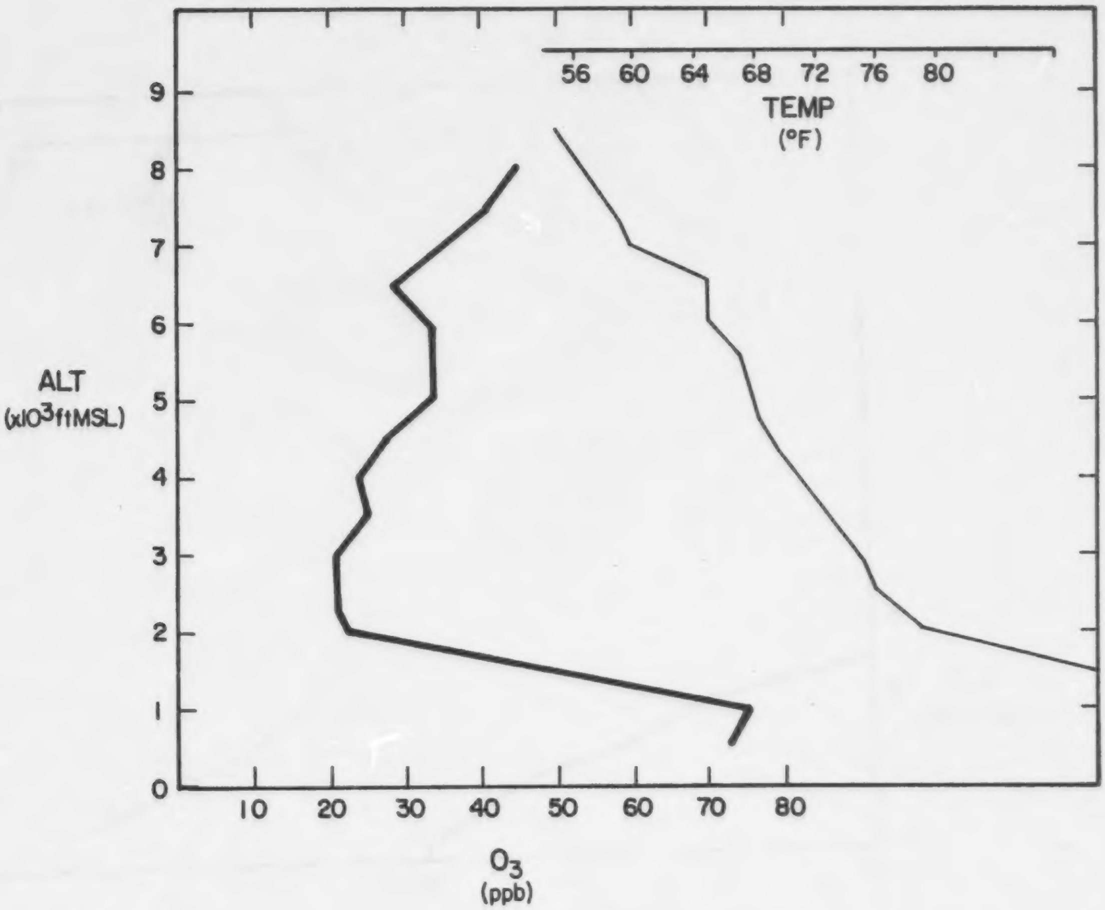


Figure B24 Vertical ozone and temperature profiles W of Houston (flt. #8: point b) at 3:10 PM on July 10, 1976.

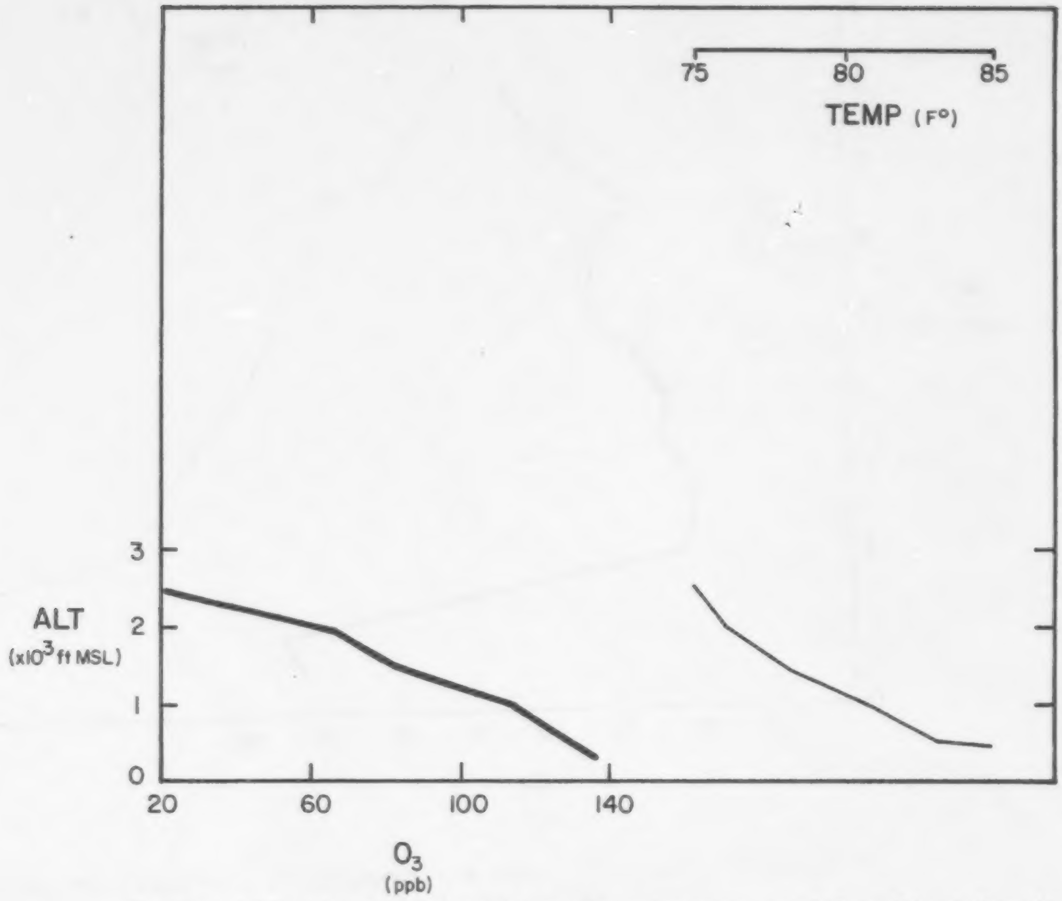


Figure B25. Vertical ozone and temperature profiles SW of Houston (Flight #8: point c) at 3:39 pm on July 10, 1976.

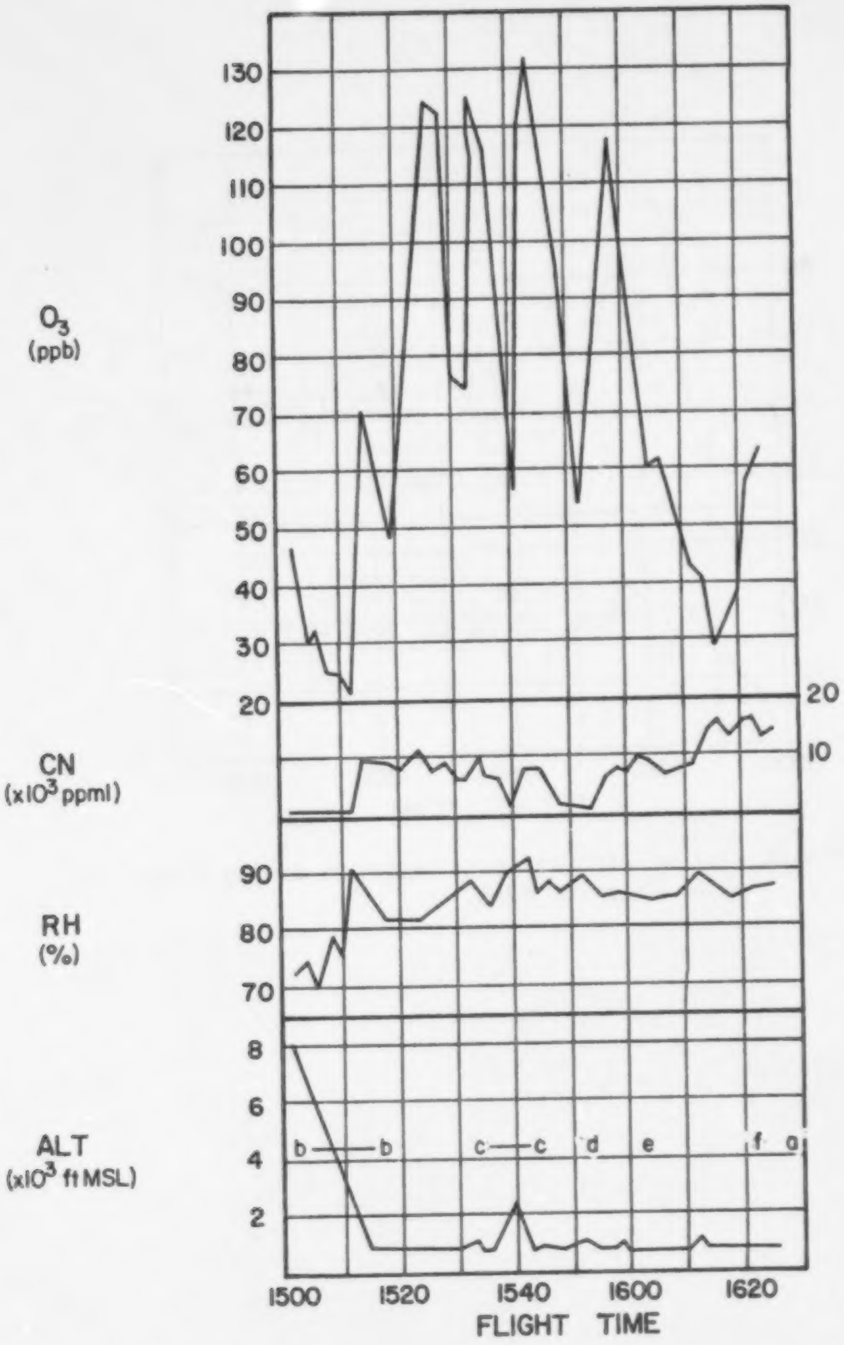


Figure B 26 Plot of aircraft data recorded during flight #8 on July 10, 1976.

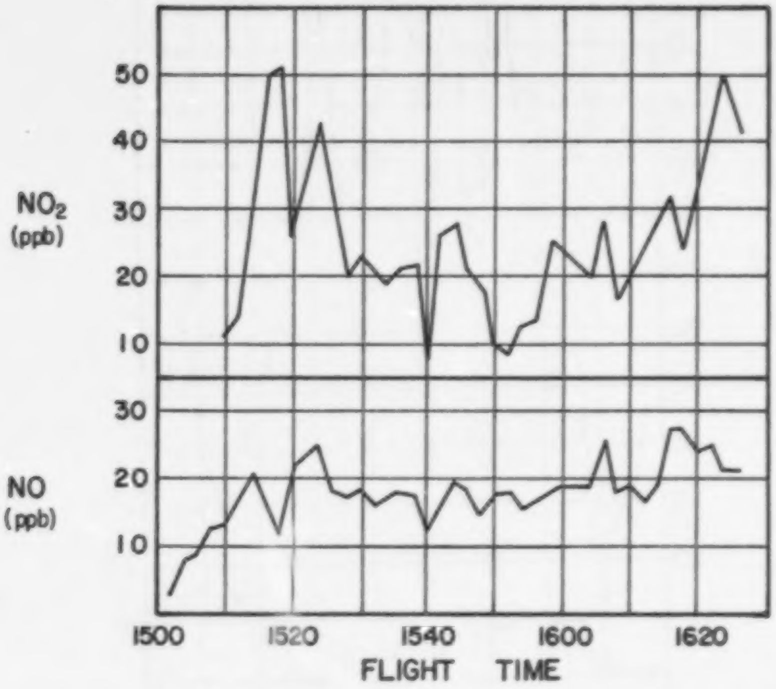


Figure B26 Plot of aircraft data recorded during flight #8 on July 10, 1976.

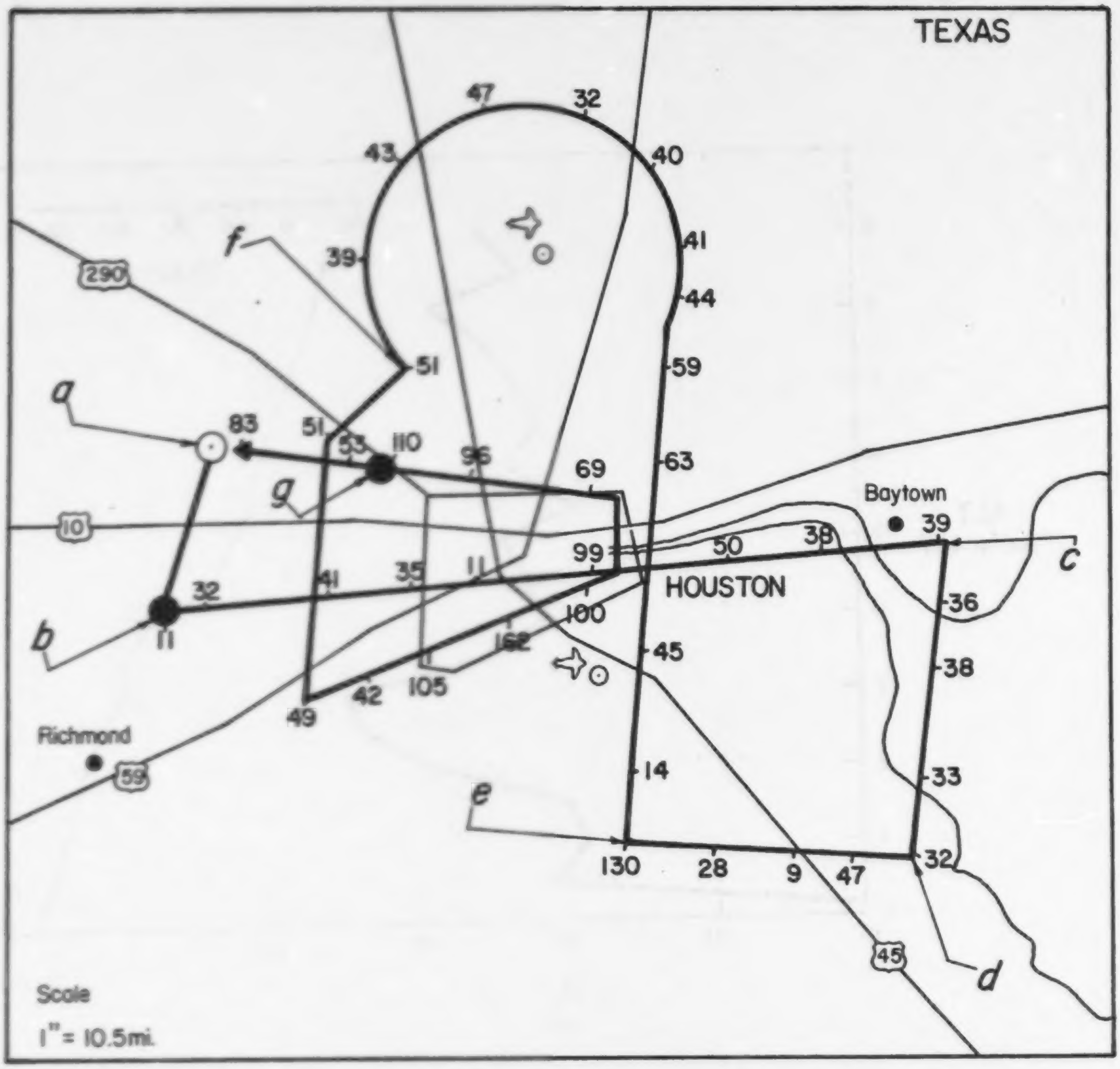

TEXAS
47
32
43
40
f
39
41
44
290
51
59
a
83
51
53
110
96
69
63
g
Baytown
39
10
99
50
38
c
41
35
11
HOUSTON
32
36
b
11
100
162
45
38
105
42
49
Richmond
33
59
14
e
130
28
9
47
32
45
d
Scale
1" = 10.5mi.

Figure B27 Flight #9 on July 12, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 8:45 to 11:25 AM

Leg
ab: 8:45 - 9:03 slant and spiral climb to 9000'
b: 9:04 - 9:25 spiral descent to 100'
bc: 9:26 - 9:49 at ∿1500'
cd: 9:50 - 9:59 at ∿1500'
de: 10:00 - 10:08 between 1000' and 1500'
ef: 10:09 - 10:35 between 1000' and 1500'
fg: 10:36 - 11:03 at ∿1000'
g: 11:04 - 11:17 spiral ascent to 4000' and spiral descent to 1000'
ga: 11:18 - 11:25 at ∿800'

WIND: IAH,100/4 HUB,065/6 WEATHER: Overcast at 8000' - 77°F

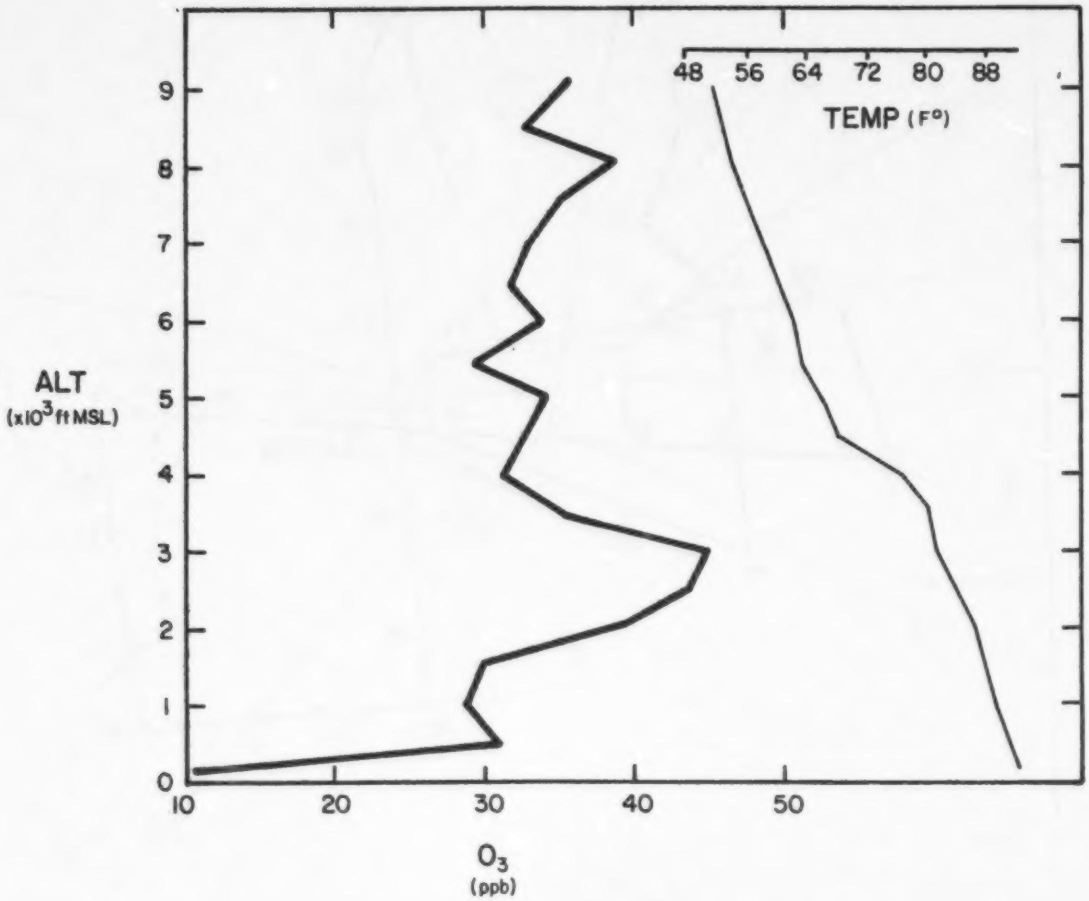


Figure B28. Vertical ozone and temperature profiles West of Houston (Flight #9: point b) at 9:04 am on July 12, 1976.

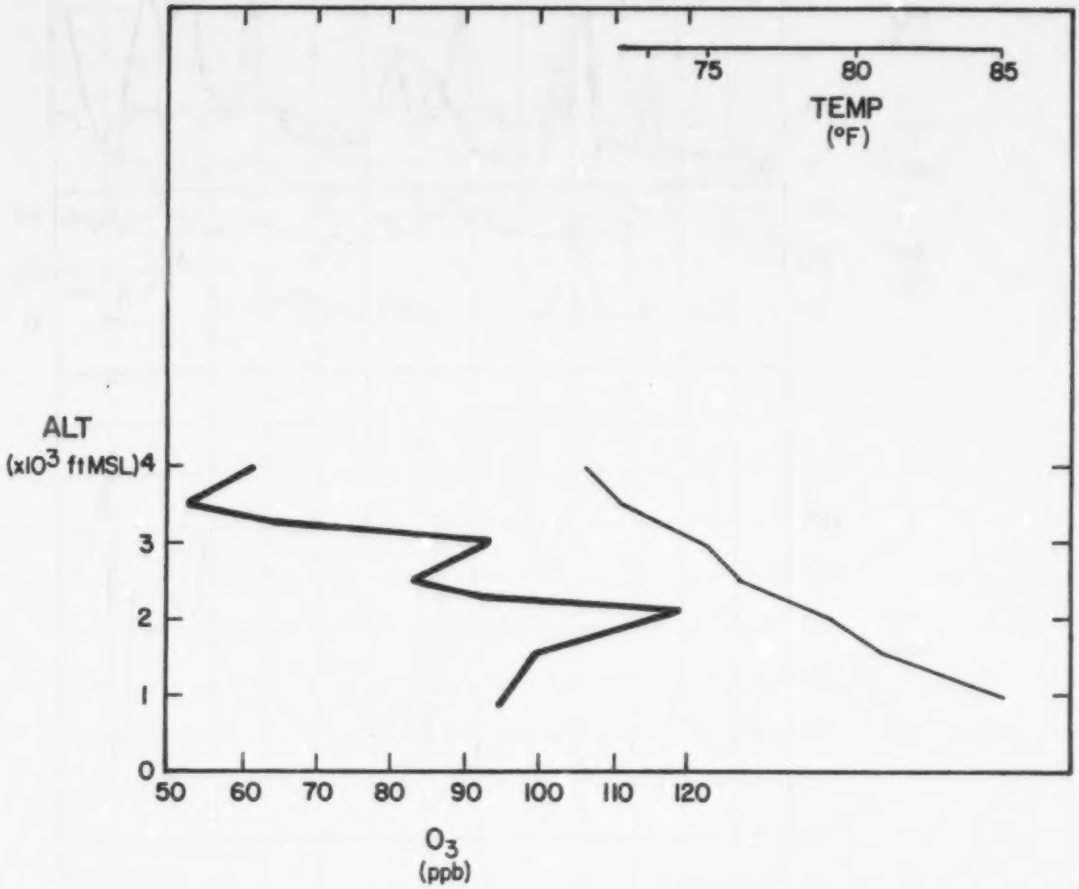


Figure B 29 Vertical ozone and temperature profiles NW of Houston (flt. #9: point g) at 11:05 AM on July 12, 1976.

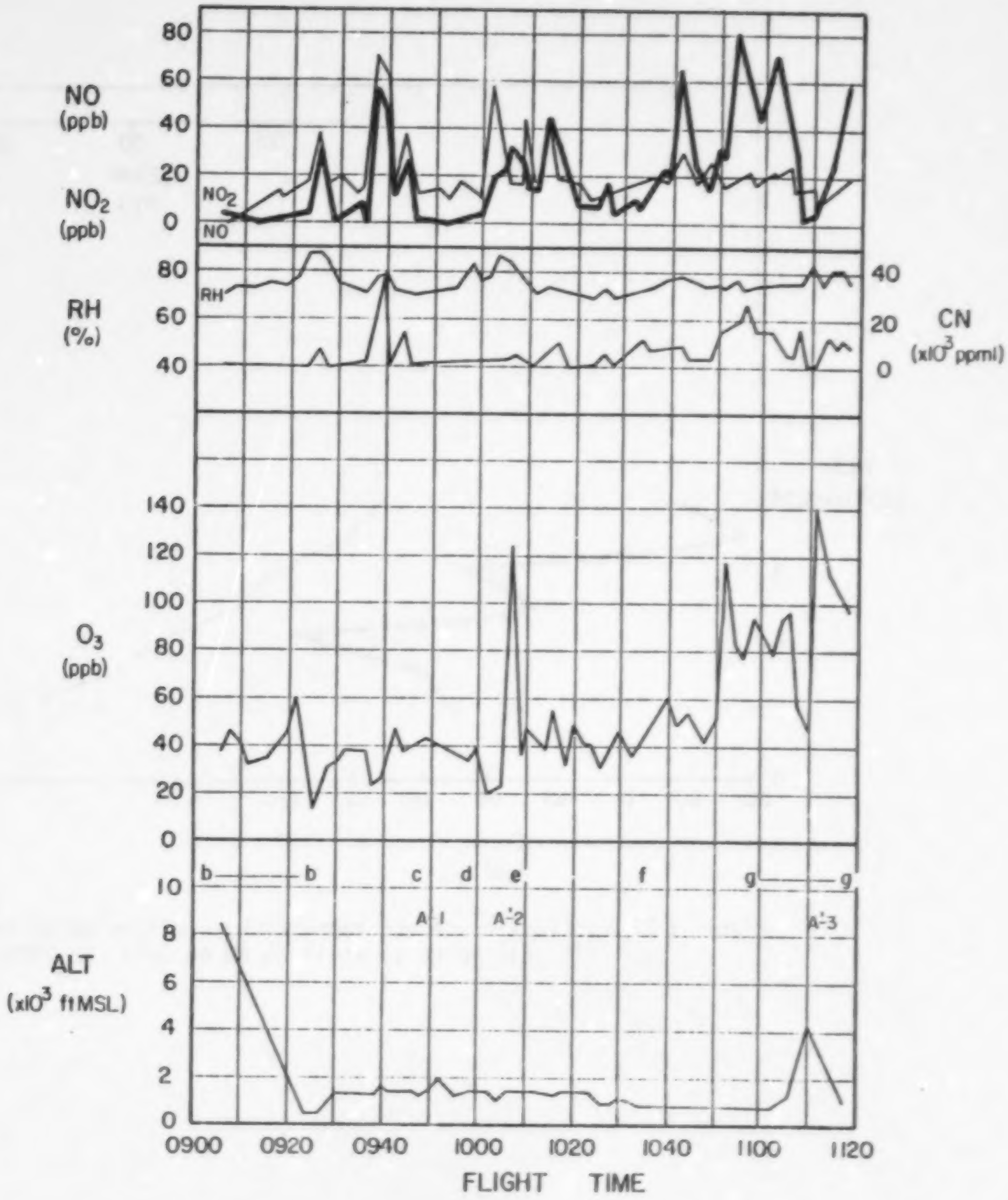


Figure B30. Plot of aircraft data recorded during Flight #9 on July 12, 1976.

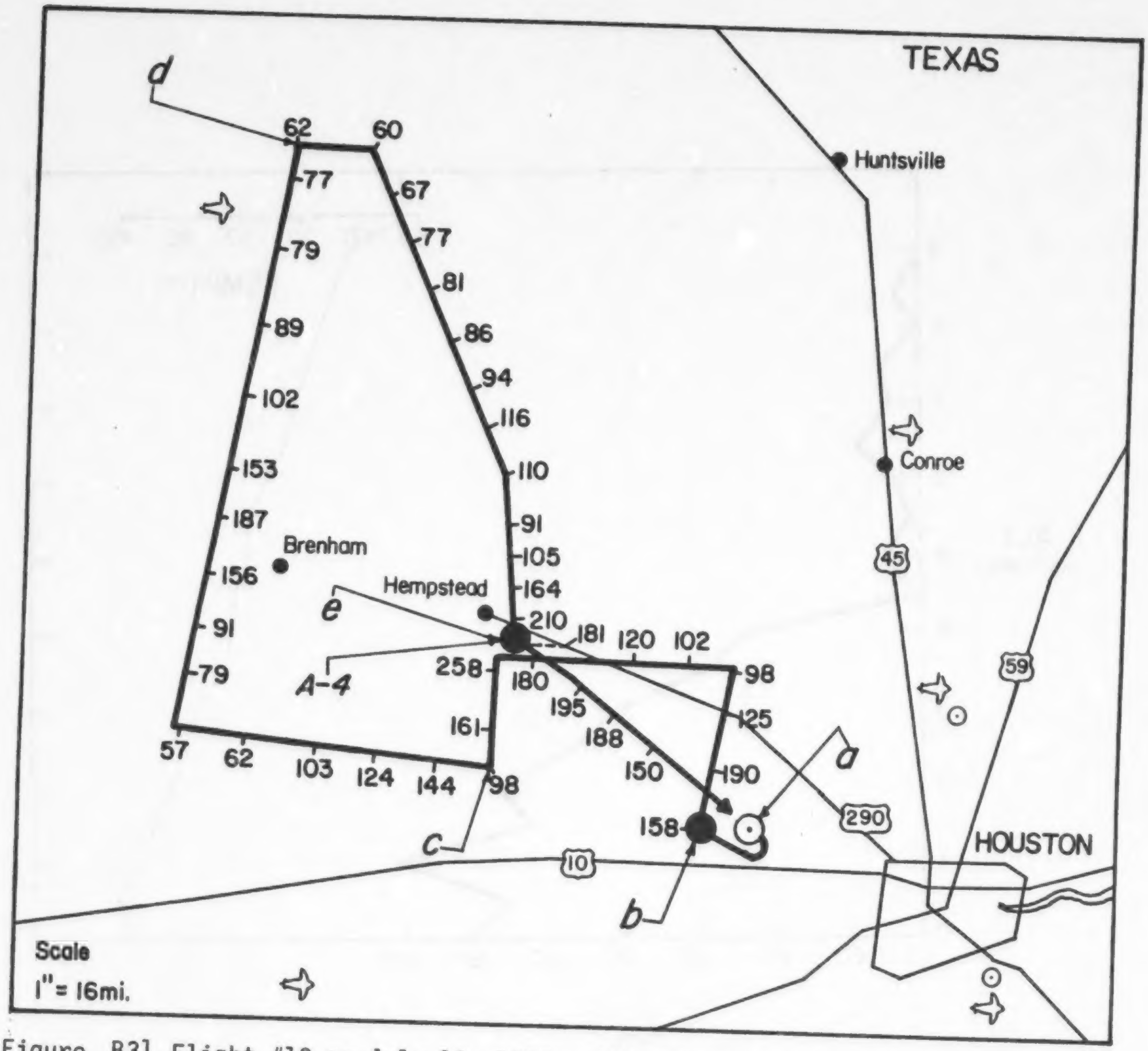

TEXAS
Huntsville
Conroe
45
59
290
10
HOUSTON
Brenham
Hempstead
d
e
A-4
a
b
c
62
60
77
67
79
77
81
89
86
94
102
116
153
110
187
91
105
156
164
91
210
181
120
102
79
258
180
98
195
125
161
188
57
62
103
124
144
98
150
190
158
Scale
1"= 16mi.

Figure B31 Flight #10 on July 12, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 3:00 to 5:50 PM

Leg
ab: 3:00 - 3:19 slant and spiral climb to 10,000' MSL
b: 3:20 - 3:40 spiral descent to 100'
bc: 3:41 - 4:03 at ~1200'
cd: 4:04 - 4:39 at ~1200'
de: 4:40 - 5:06 at ~1200'
e: 5:07 - 5:20 spiral ascent to 5000' and spiral descent to 700'
ea: 5:21 - 5:50 at ~1200'

WIND: IAH,100/10 HUB,070/8

WEATHER: Broken clouds at 10,000', overcast at 25,000' - hot, 86 - 101°F

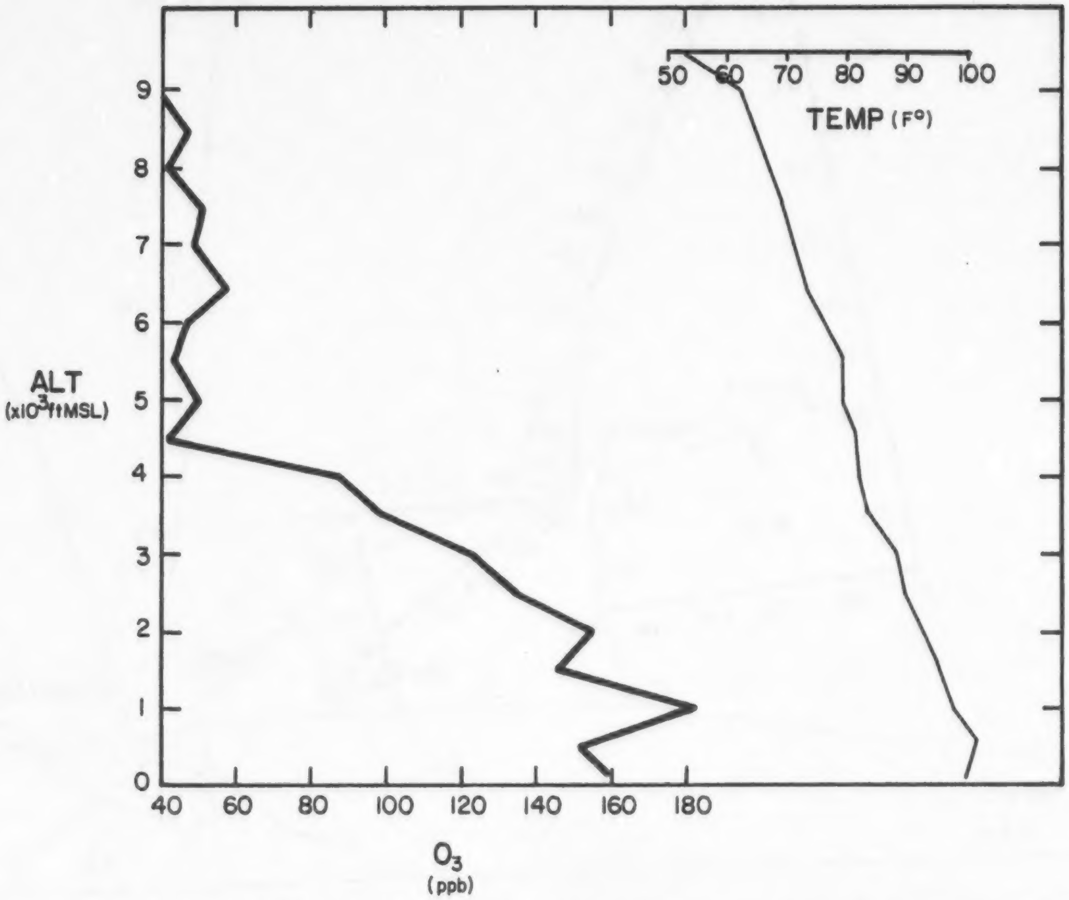


Figure B32. Vertical ozone and temperature profiles NW of Houston (Flight #10: point b) at 3:20 pm on July 12, 1976.

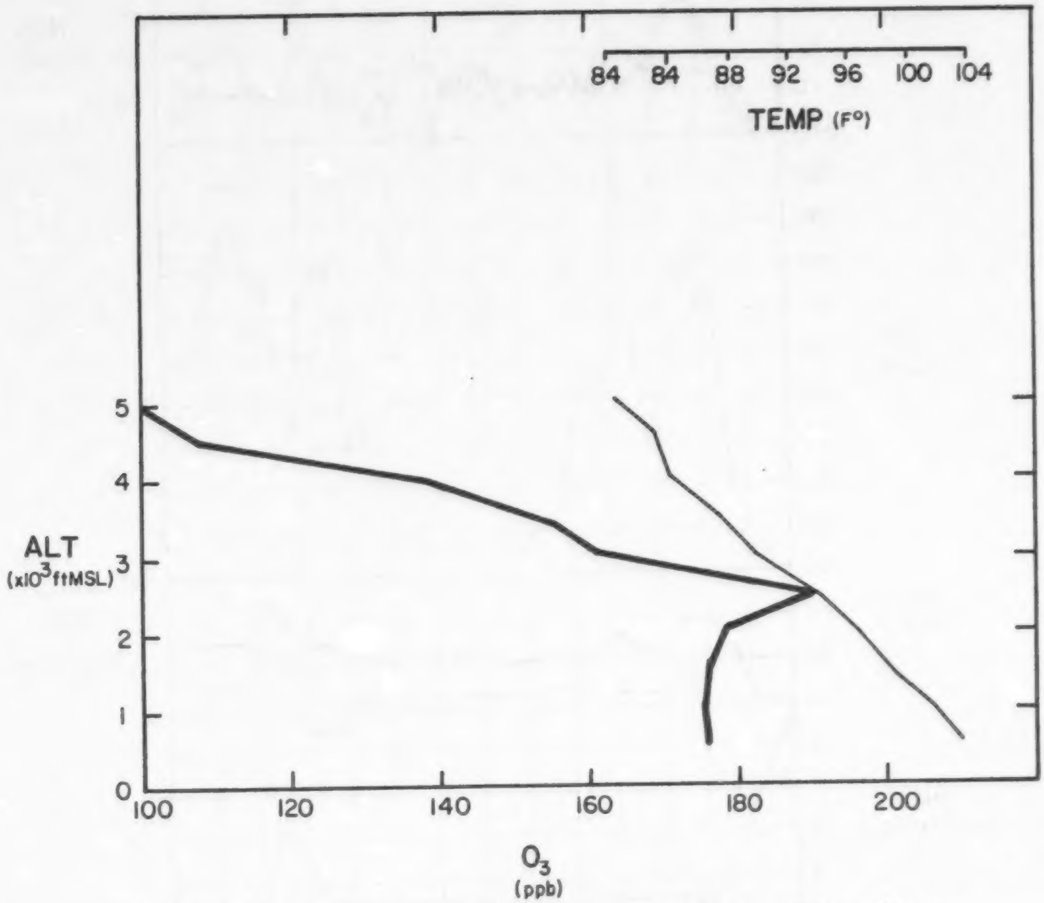


Figure B33. Vertical ozone and temperature profiles SW of Hempstead, TX. (Flight #10: point e) at 5:10 pm on July 12, 1976.

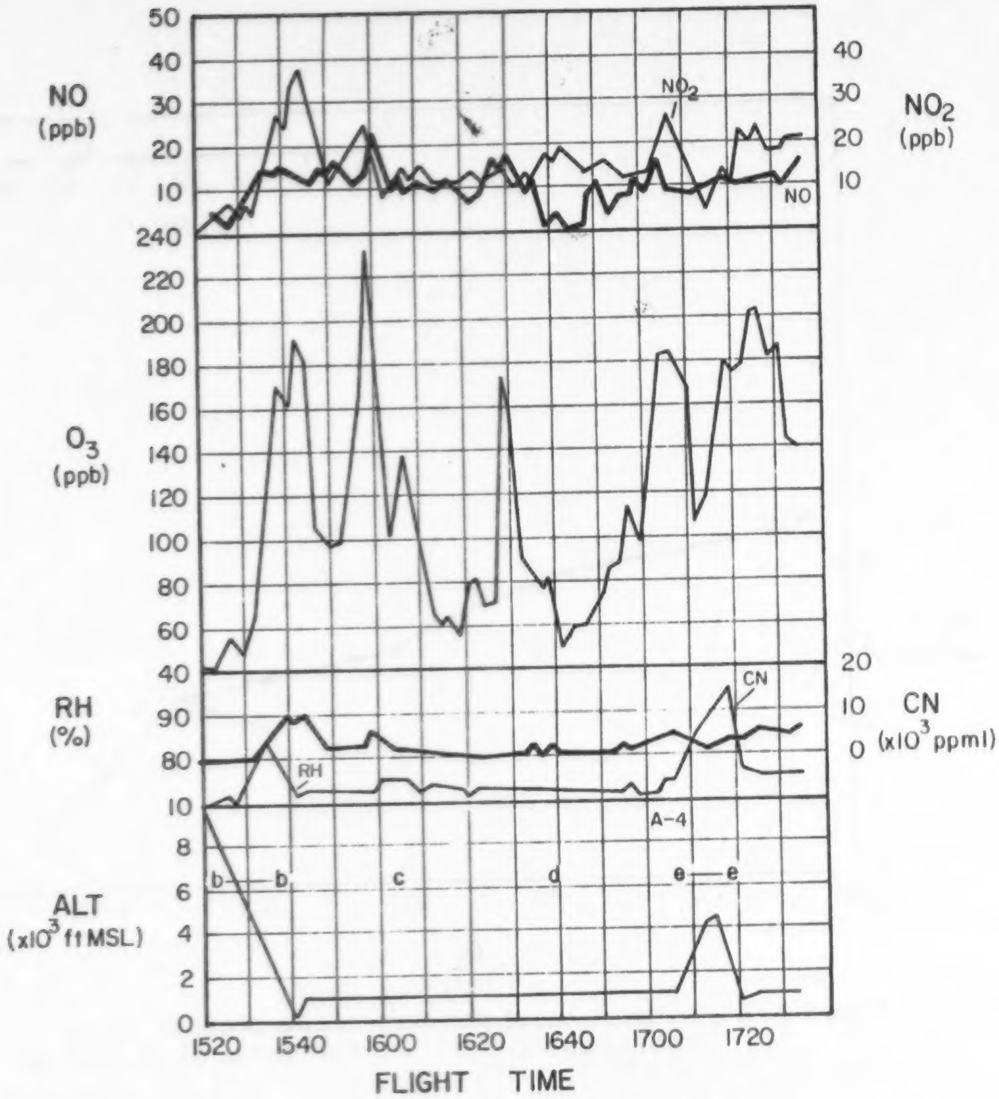


Figure B34. Plot of aircraft data recorded during Flight #10 on July 12, 1976.

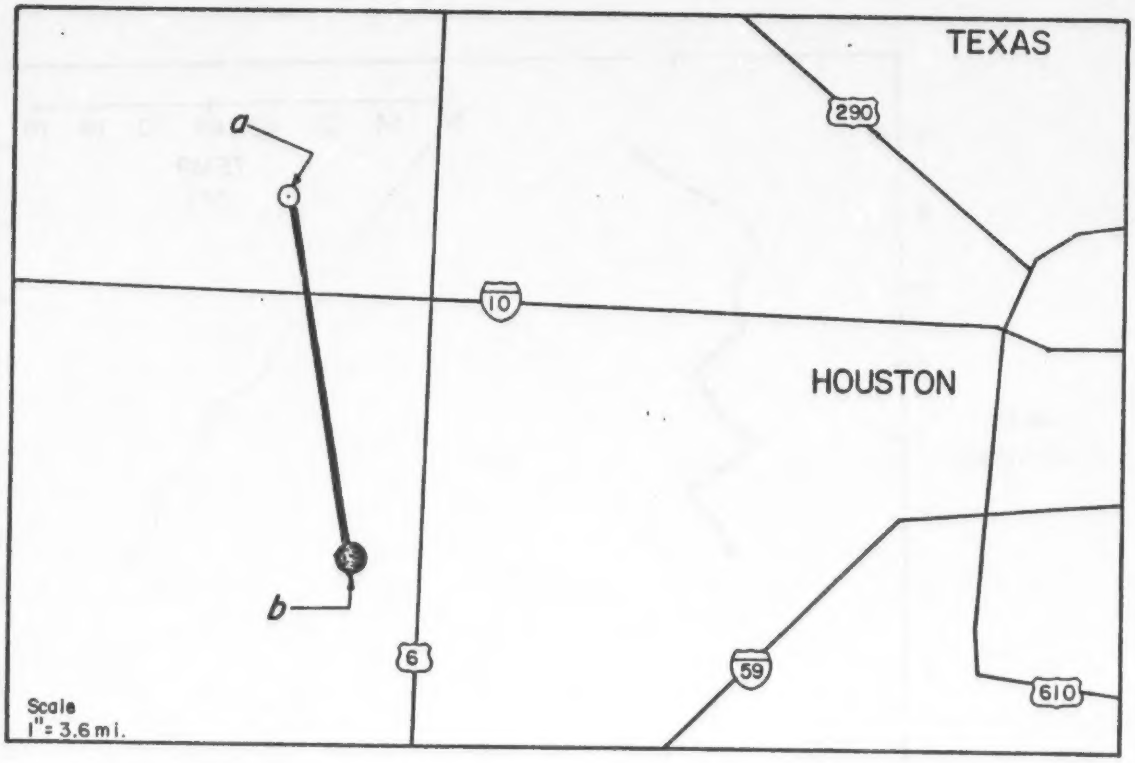

TEXAS
290
a
10
HOUSTON
b
6
59
610
Scale
1" = 3.6 mi.

Figure B35. Flight #10 on July 13, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 9:18 - 9:35

WIND: HUB, 190/6

WEATHER: Broken clouds

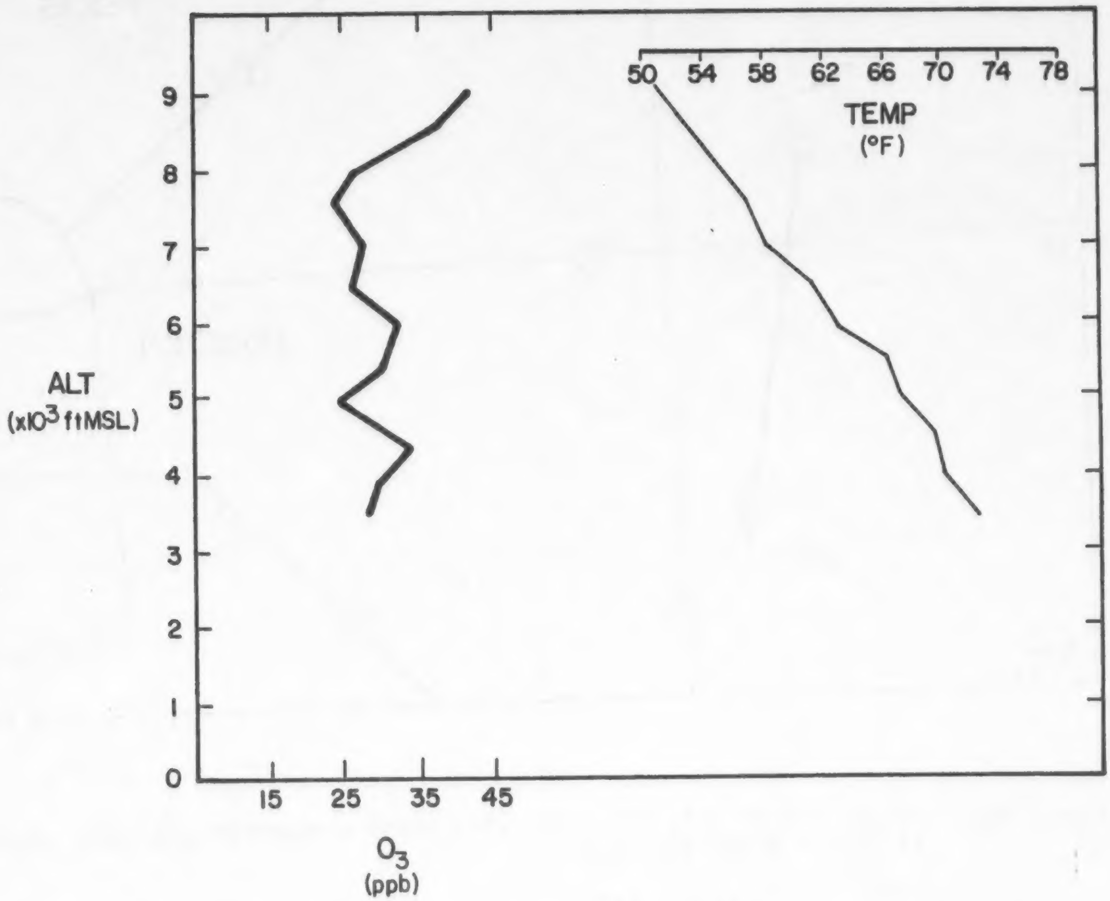


Figure B36 Vertical ozone and temperature profiles W of Houston (flt. #11: point) at 9:20 AM on July 13, 1976.

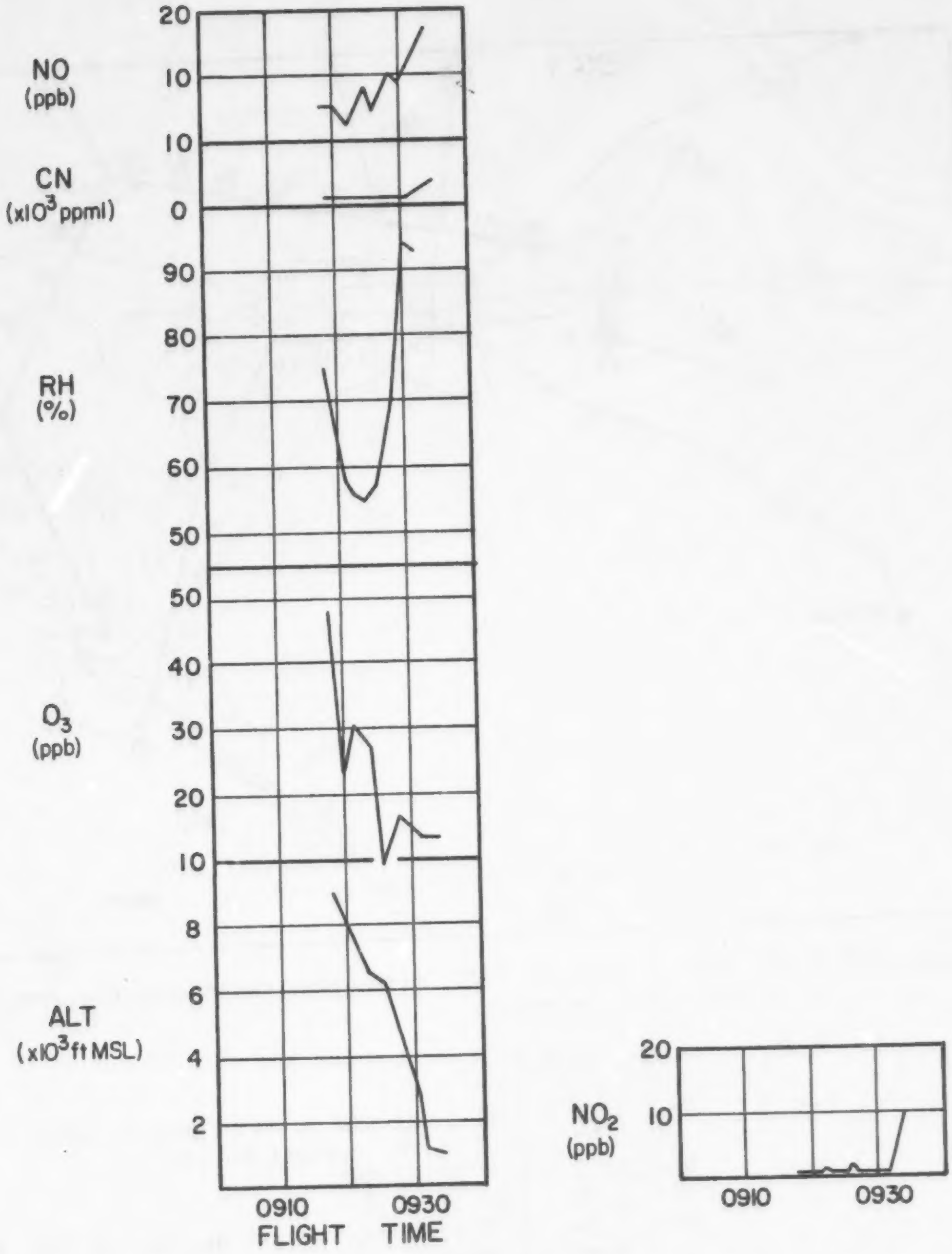


Figure B37 Plot of aircraft data recorded during flight #11 on July 13, 1976.

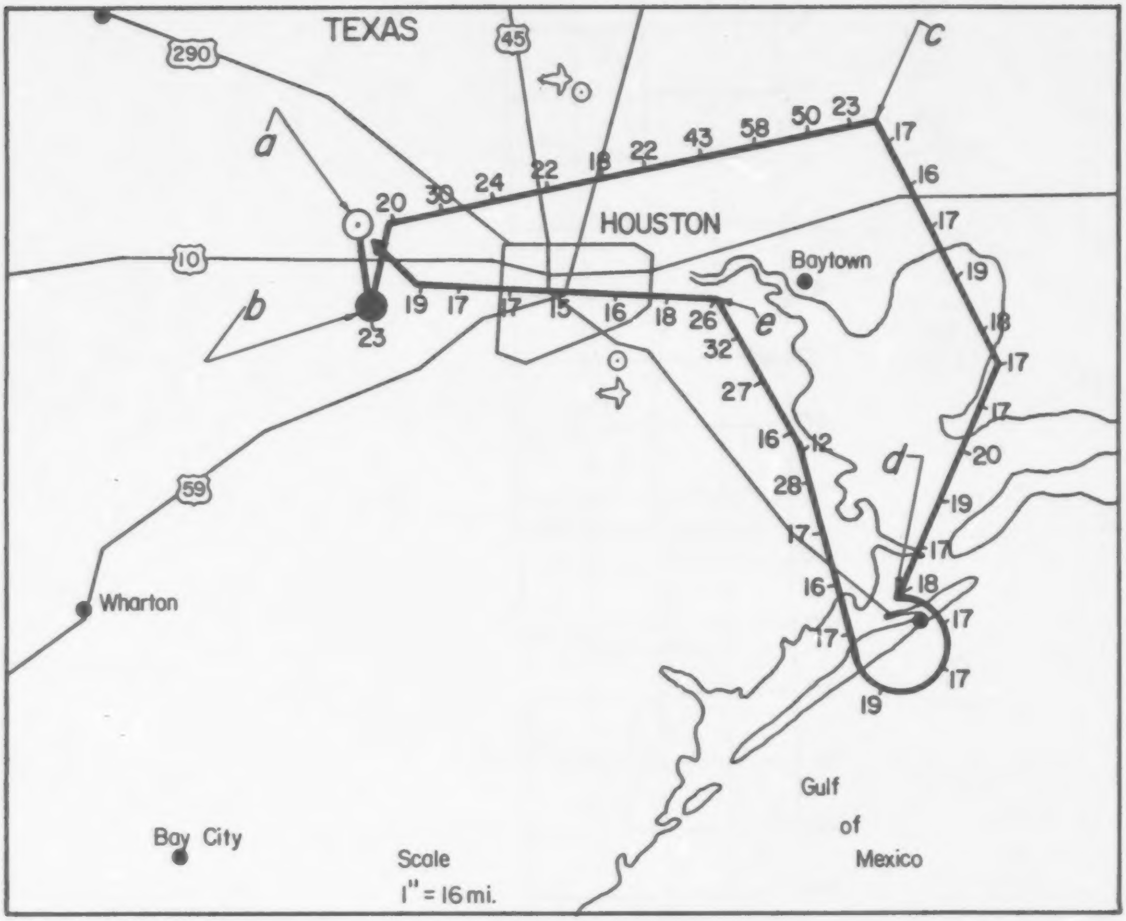

TEXAS
290
45
10
59
HOUSTON
Baytown
Wharton
Bay City
Gulf
of
Mexico
Scale
1" = 16 mi.
a
b
c
d
e
20
30
24
22
18
22
43
58
50
23
17
16
17
19
18
17
17
20
19
17
18
17
17
19
17
16
17
28
16
12
27
32
26
18
16
15
17
17
19
23

Figure B38 Flight #12 on July 13, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 5:33 - 8:05 PM

Leg
ab: 5:33 - 5:51 slant and spiral climb to 9000' MSL
b: 5:52 - 6:12 spiral descent to 100'
bc: 6:13 - 6:37 at ∿1500'
cd: 6:38 - 7:04 at ∿1500'
de: 7:05 - 7:33 at ∿1500' (slant descent to 900' over Baycliff Power Plant)
ea: 7:34 - 8:05 slant climb to 5500' and slant descent to landing at Lakeside

WIND: IAH,090/13 HUB,100/10

WEATHER: Broken clouds at 5000' - 71^{o}F

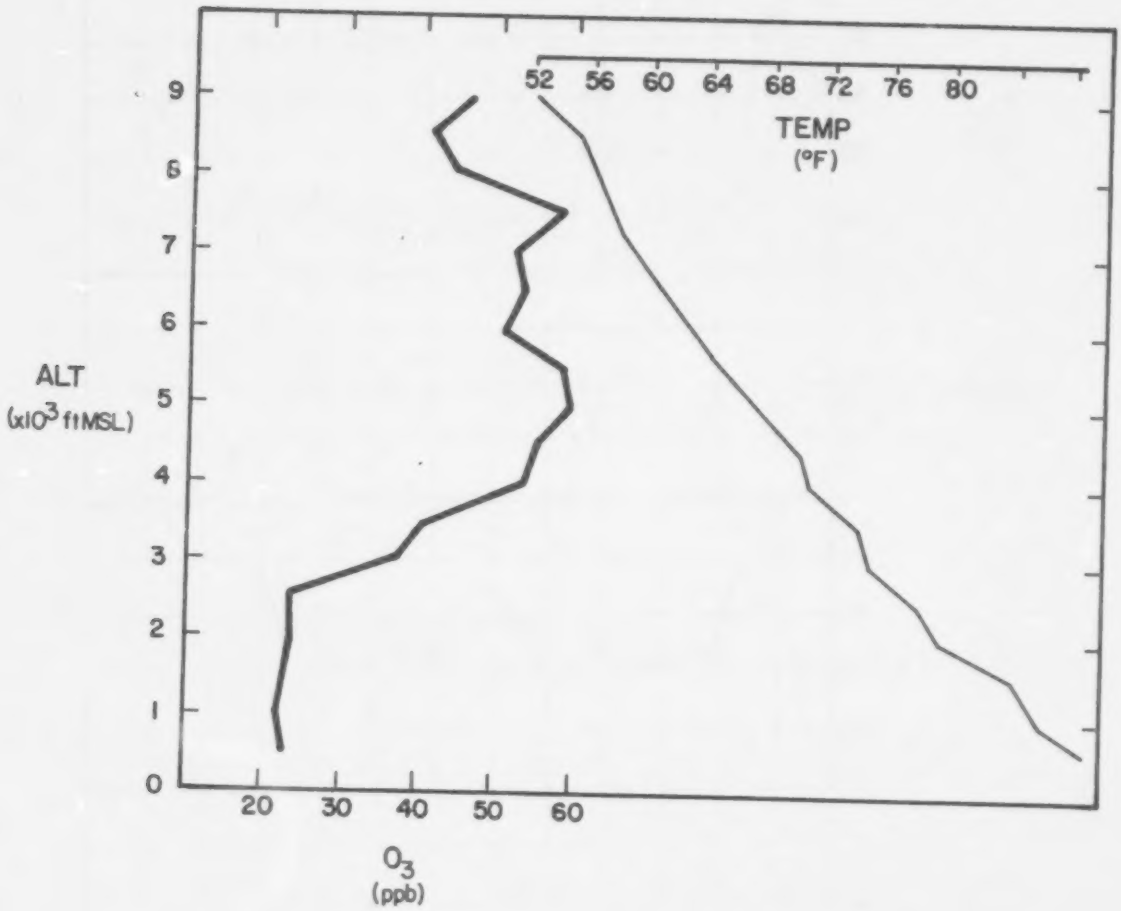


Figure B 39 Vertical ozone and temperature profiles W of Houston (flt. #12: point b) at 6:00 PM on July 13, 1976.

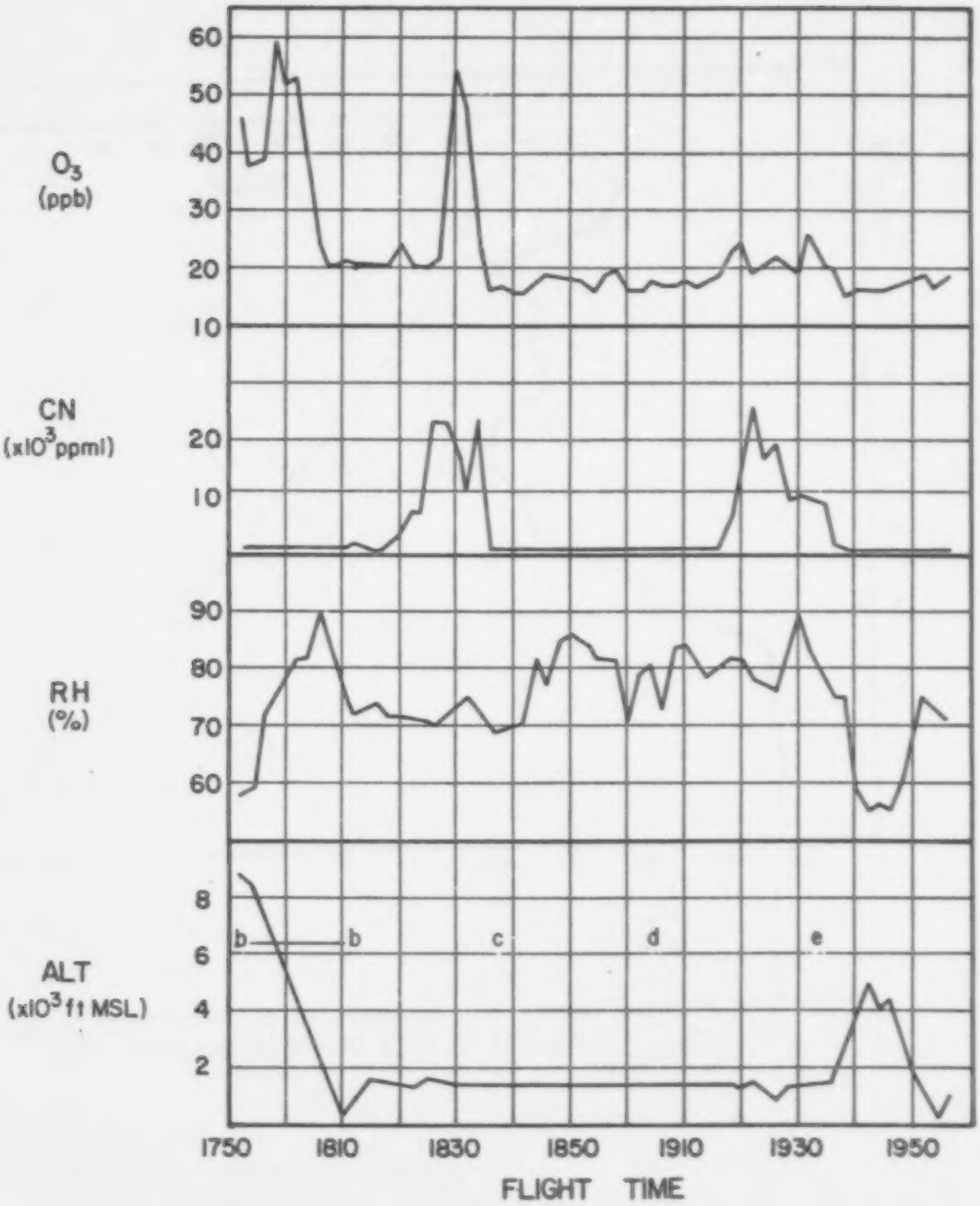


Figure B 40 Plot of aircraft data recorded during flight #12 on July 13, 1976.

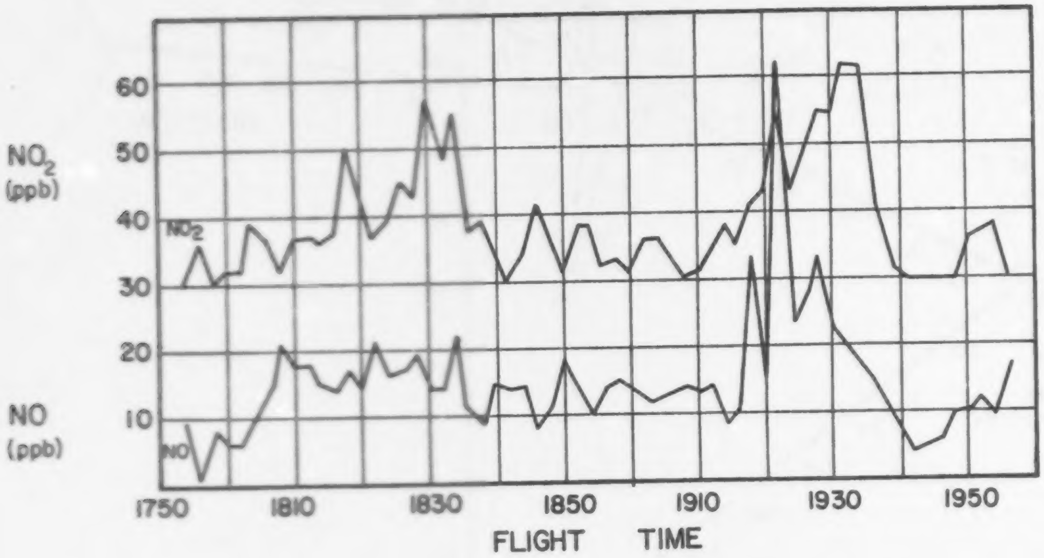


Figure B40 Plot of aircraft data recorded during flight #12 on July 13, 1976.

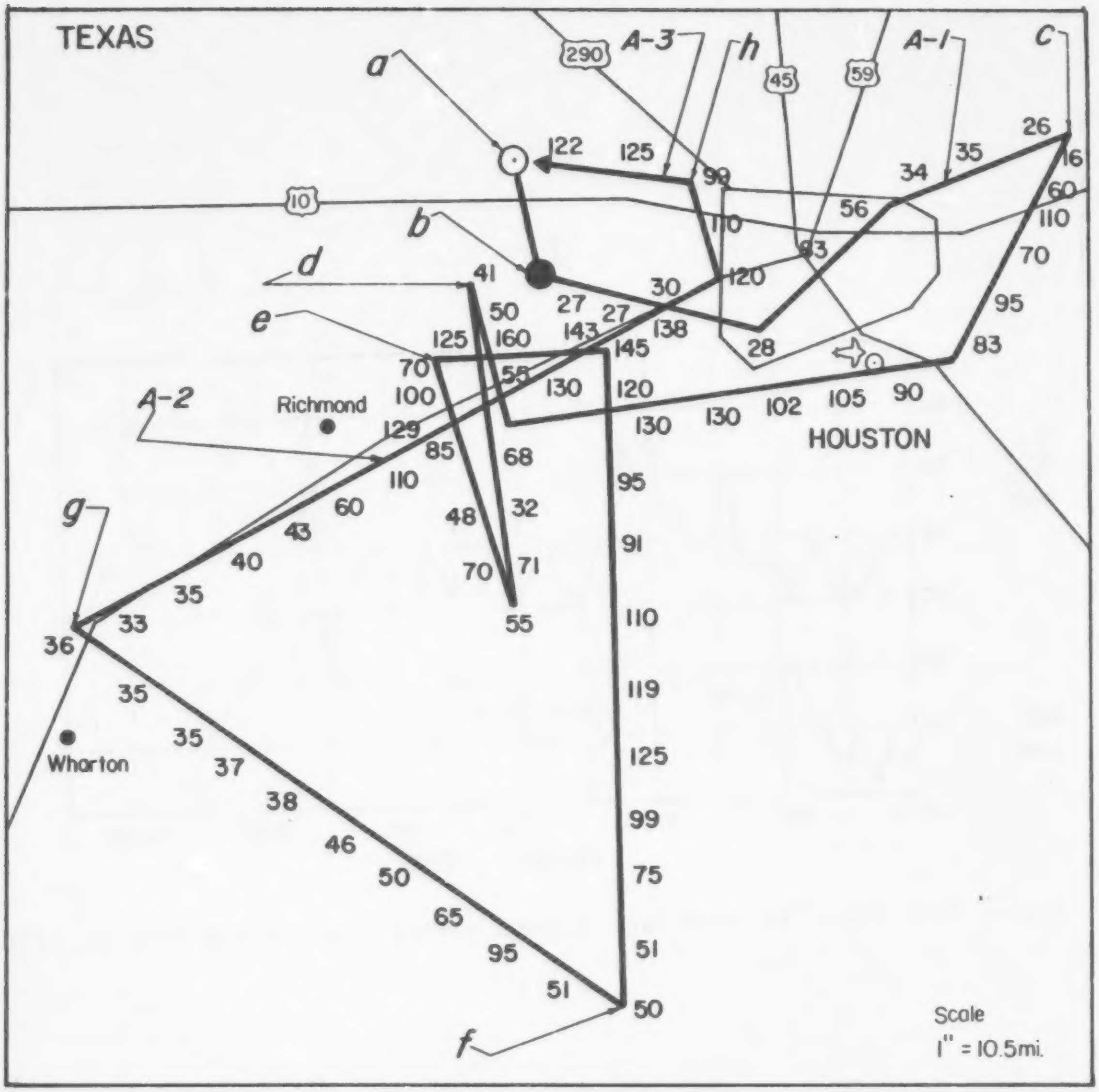

TEXAS
a
290
A-3
h
45
59
A-1
c
122
125
99
35
34
26
16
10
56
60
110
b
110
83
70
d
41
120
30
95
e
50
27
27
125
160
143
138
145
28
83
70
55
130
120
A-2
100
Richmond
129
130
130
102
105
90
HOUSTON
85
68
110
95
60
48
32
43
40
91
70
71
35
g
33
55
110
36
35
119
35
Wharton
37
125
38
99
46
50
75
65
95
51
51
50
f
Scale
1" = 10.5mi.

Figure B41 Flight #13 on July 14, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 11:40 AM - 2:35 PM

Leg
ab: 11:40 - 11:57 slant and spiral slimb to 9000' MSL
b: 11:58 - 12:15 spiral descent to 100'
bc: 12:16 - 12:37 at ~800'
cd: 12:38 - 1:01 at ~800'
de: 1:02 - 1:22 at ~800'
ef: 1:23 - 1:45 at ~800'
fg: 1:46 - 2:01 at ~800'
gh: 2:02 - 2:25 at ~800'
ha: 2:26 - 2:35 at ~800'

WIND: IAH,080/6 HUB,060/8 WEATHER: Broken clouds at 2500'- visibility 2-5 miles in haze and smoke- 75°F

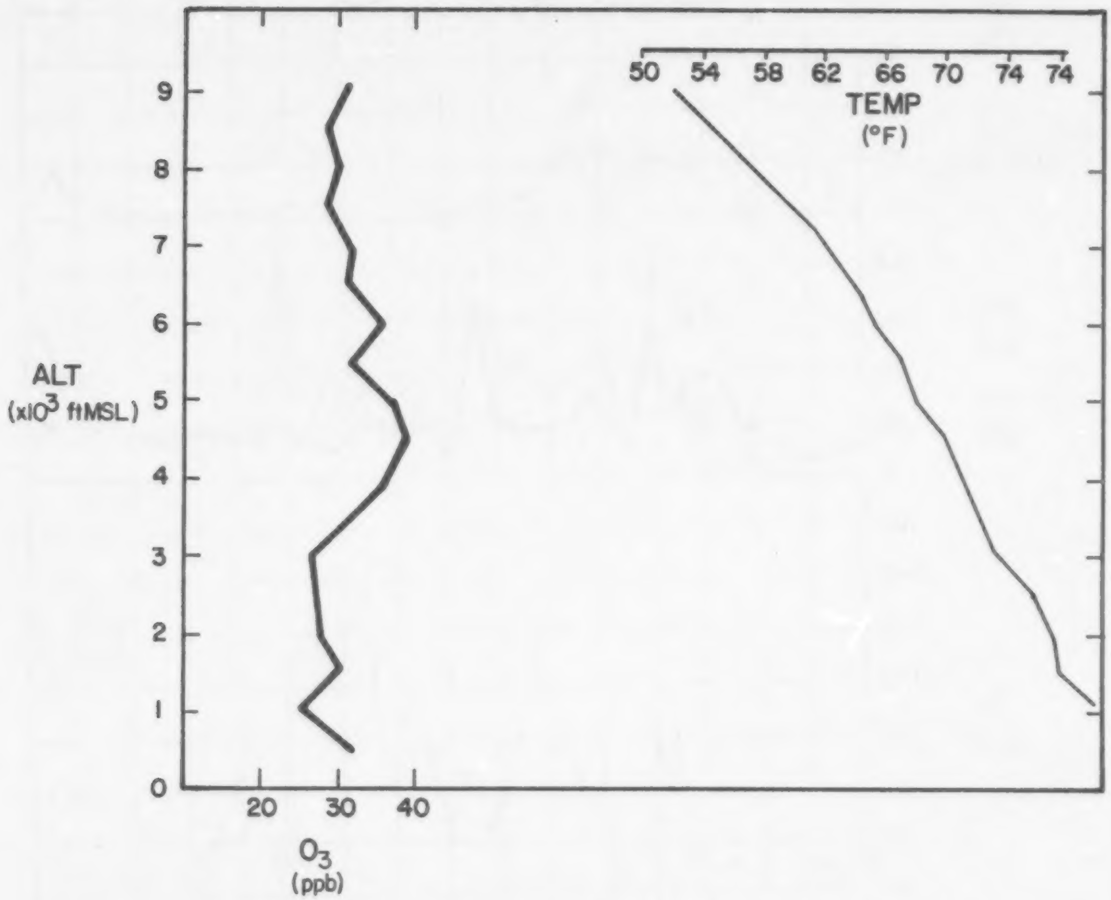


Figure B 42 Vertical ozone and temperature profiles W of Houston (flt. #13: point b) at 12:05 PM on July 14, 1976.

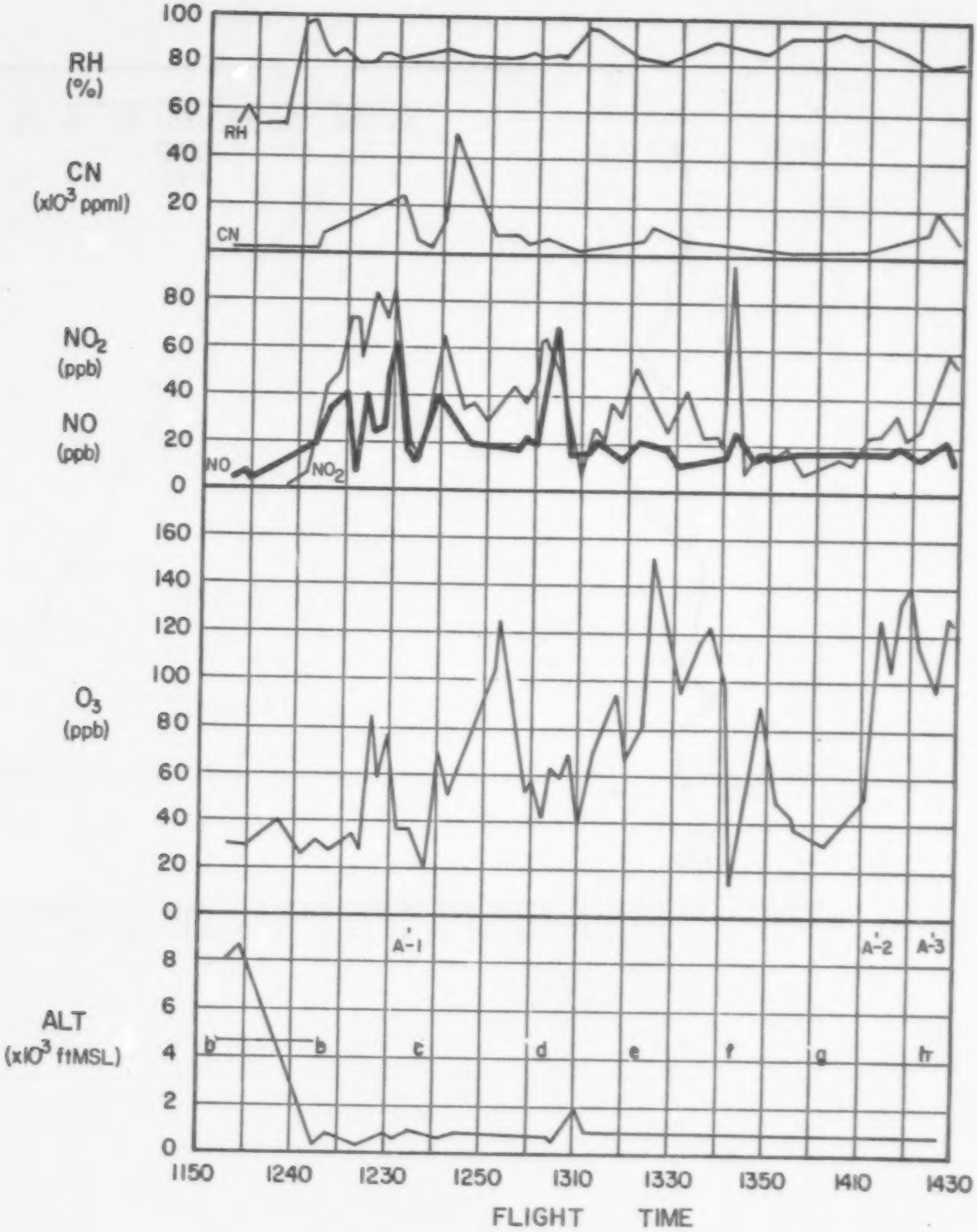


Figure B43 Plot of aircraft data recorded during Flight #13 on July 14, 1976.

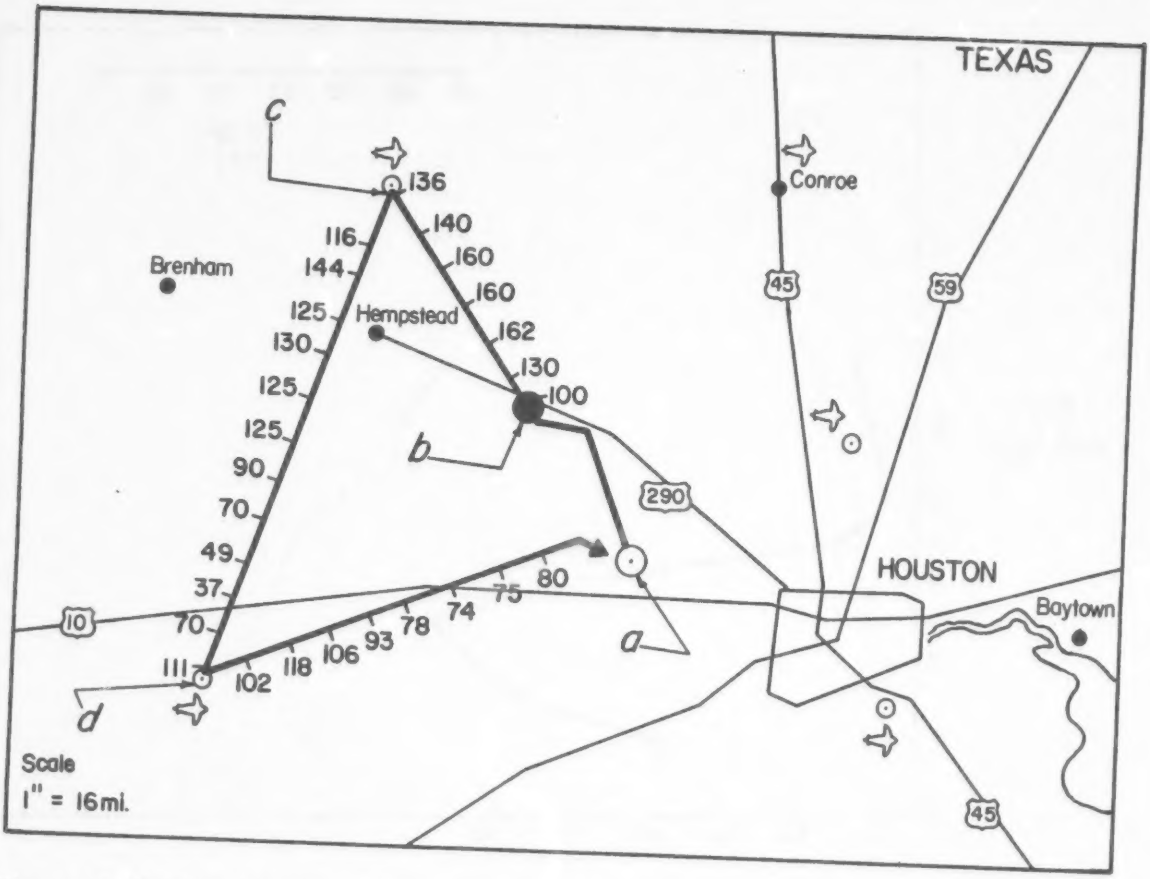

TEXAS
c
136
140
116
160
Brenham
144
160
125
Hempstead
162
130
130
125
100
125
b
90
70
49
37
80
75
70
74
78
93
106
118
111
102
d
a
Conroe
45
59
290
10
HOUSTON
Baytown
45
Scale
1" = 16mi.

Figure B 44 Flight #14 on July 14, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 4:20 to 5:40 PM

Leg	ab:	4:20 - 4:30 slant and spiral climb to 6000' MSL
	b:	4:31 - 4:42 spiral descent to 200'
	bc:	4:43 - 4:54 at ∿2000'
	cd:	4:55 - 5:16 at ∿2000'
	da:	5:17 - 5:40 at ∿1000'

WIND: IAH,110/9 HUB,180/10

WEATHER: Broken clouds at 4000' - high overcast - 6 miles visibility in haze and smoke - 89°F

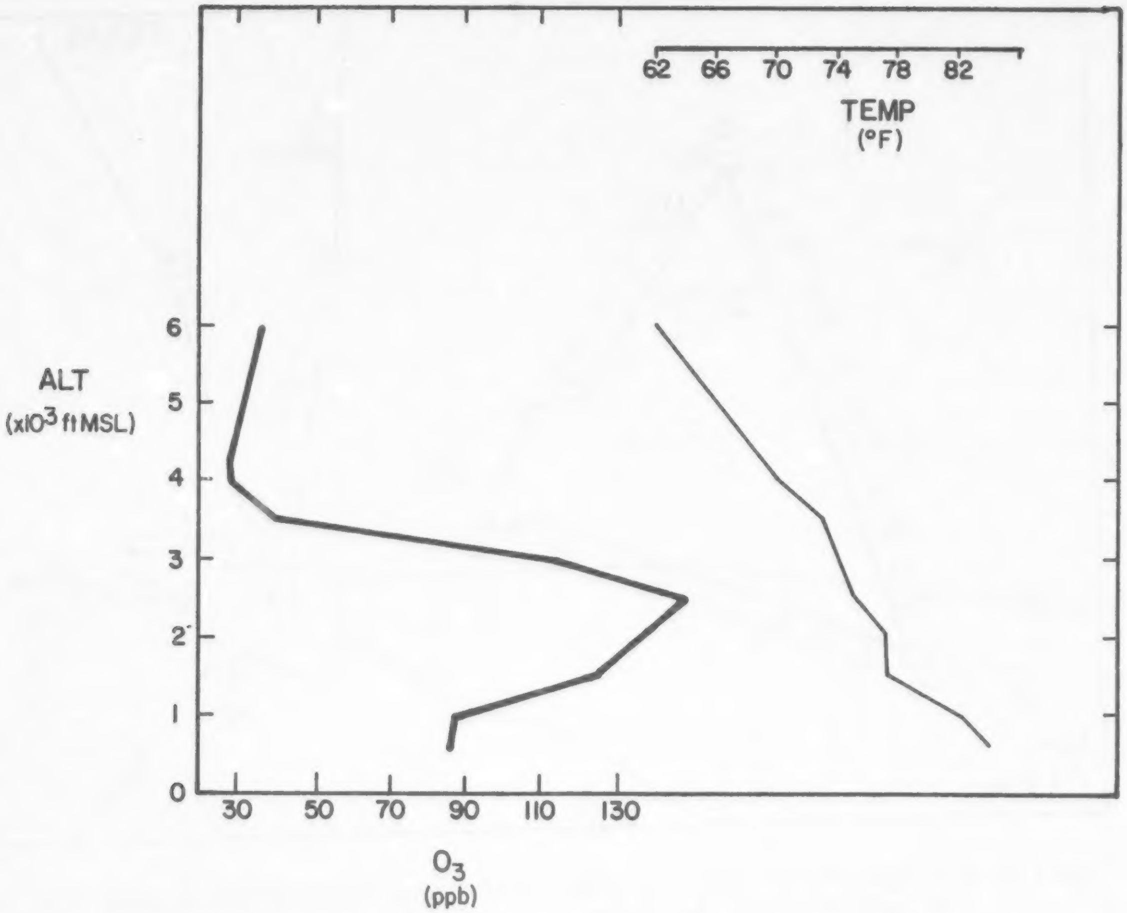


Figure B 45 Vertical ozone and temperature profiles NW of Houston (flt. #14: point b) at 4:35 PM on July 14, 1976.

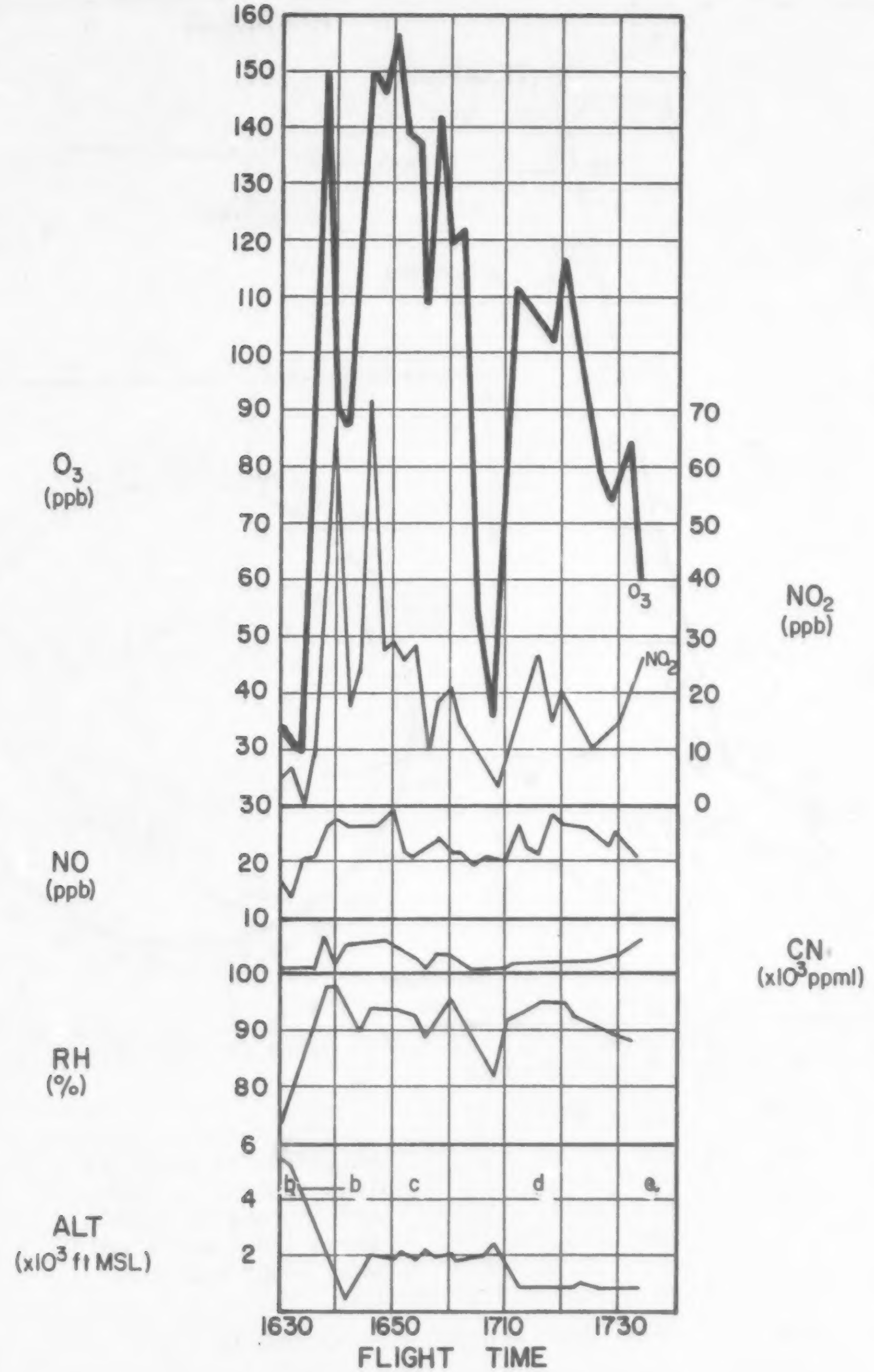


Figure B46 Plot of aircraft data recorded during flight #14 on July 14, 1976.

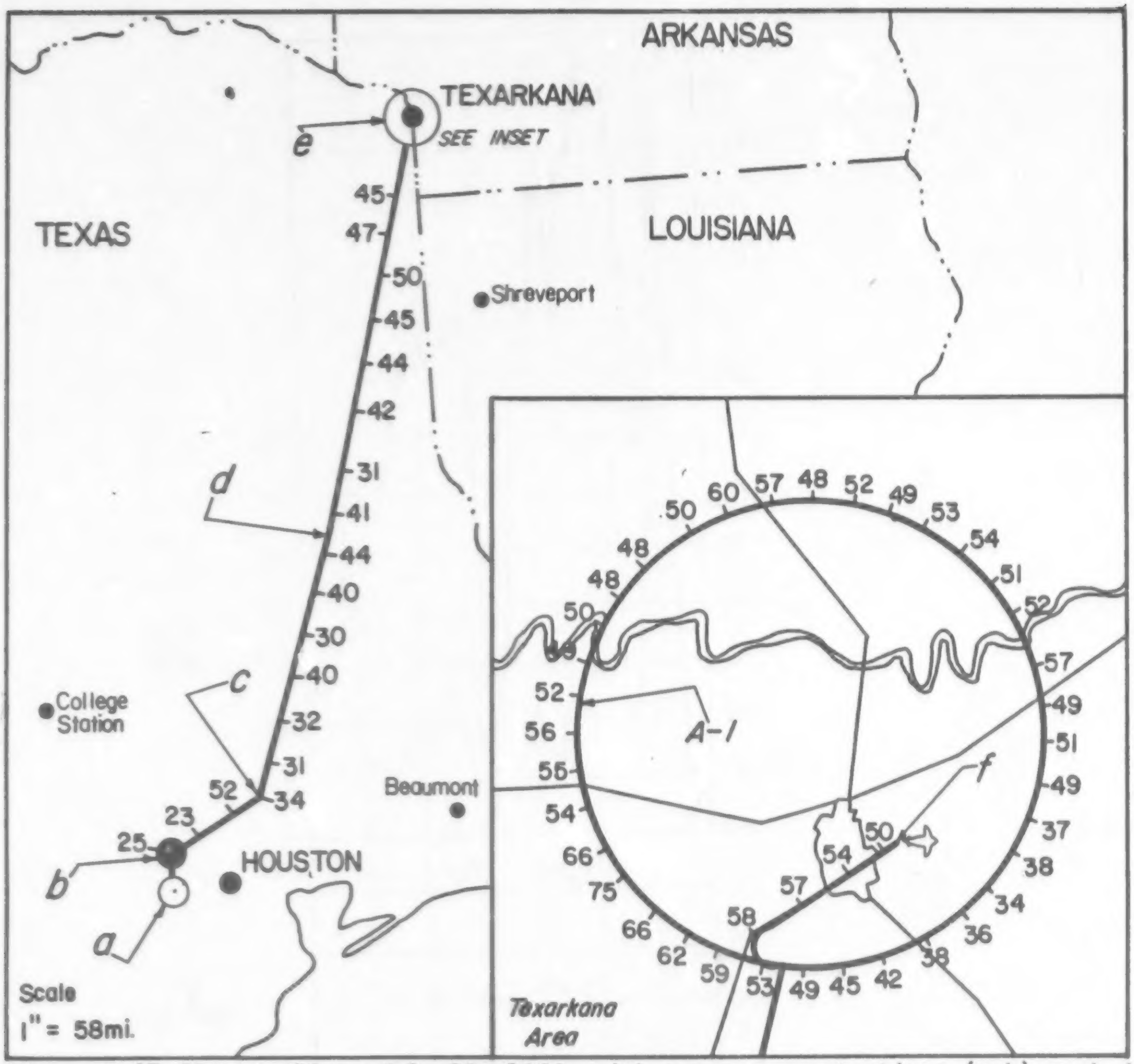

ARKANSAS
TEXARKANA
SEE INSET
e
TEXAS
LOUISIANA
Shreveport
45
47
50
45
44
42
31
41
44
40
30
40
32
31
34
52
23
25
d
c
b
a
College Station
Beaumont
HOUSTON
Scale
1" = 58mi.
50
60
57
48
52
49
53
54
51
52
57
49
51
49
37
38
34
36
38
42
45
49
53
59
62
66
75
66
54
55
56
52
50
48
48
A-1
f
50
54
57
58
Texarkana Area

Figure B 47 Flight #15 on July 15, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 11:27 AM - 2:07 PM

Leg ab: 11:27 - 11:34 slant climb to 4000' MSL
b: 11:35 - 11:41 spiral descent to 3000'
bc: 11:42 - 12:02 slant descent to 1500'
cd: 12:03 - 12:27 between 1500' and 4000'
de: 12:28 - 1:30 between 1500' and 3000'
ef: 1:31 - 2:07 at 1000'

WIND: IAH,130/7 HUB,180/13 TKK,050/10

WEATHER: Broken clouds at ~5000' - 84^{O}F

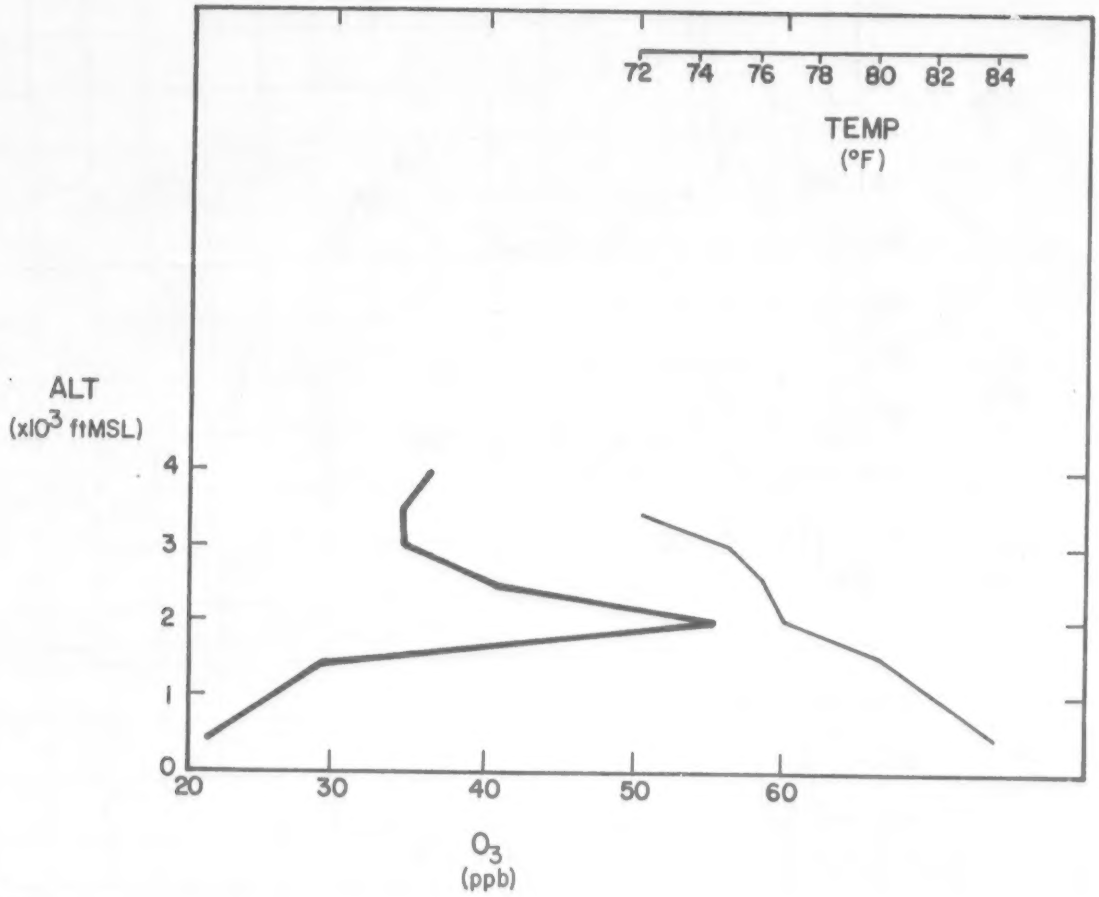


Figure B 48 Vertical ozone and temperature profiles NW of Houston (flt. #15: point b) at 11:35 AM on July 15, 1976.

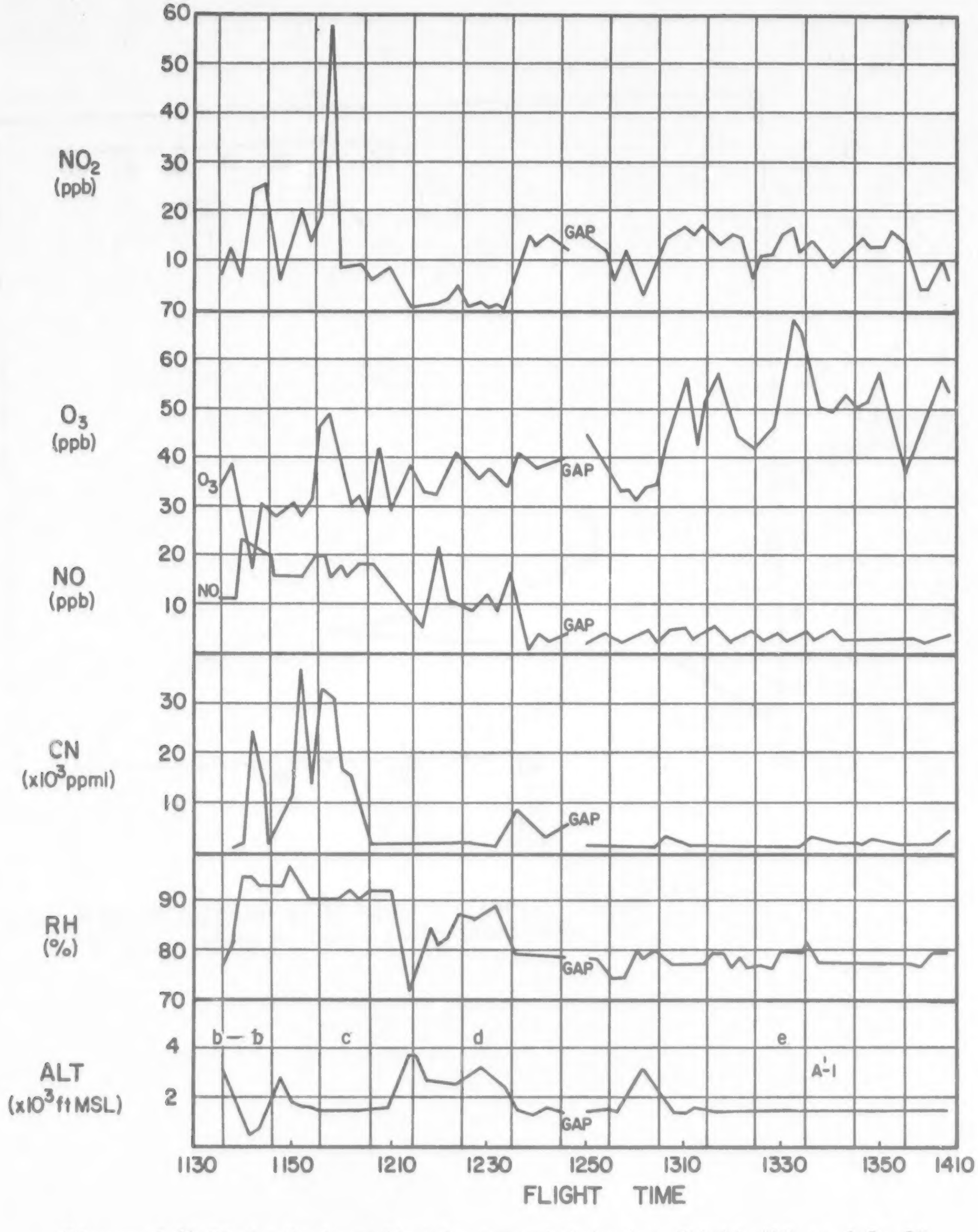


Figure B 49 Plot of aircraft data recorded during flight #15 on July 15, 1976.

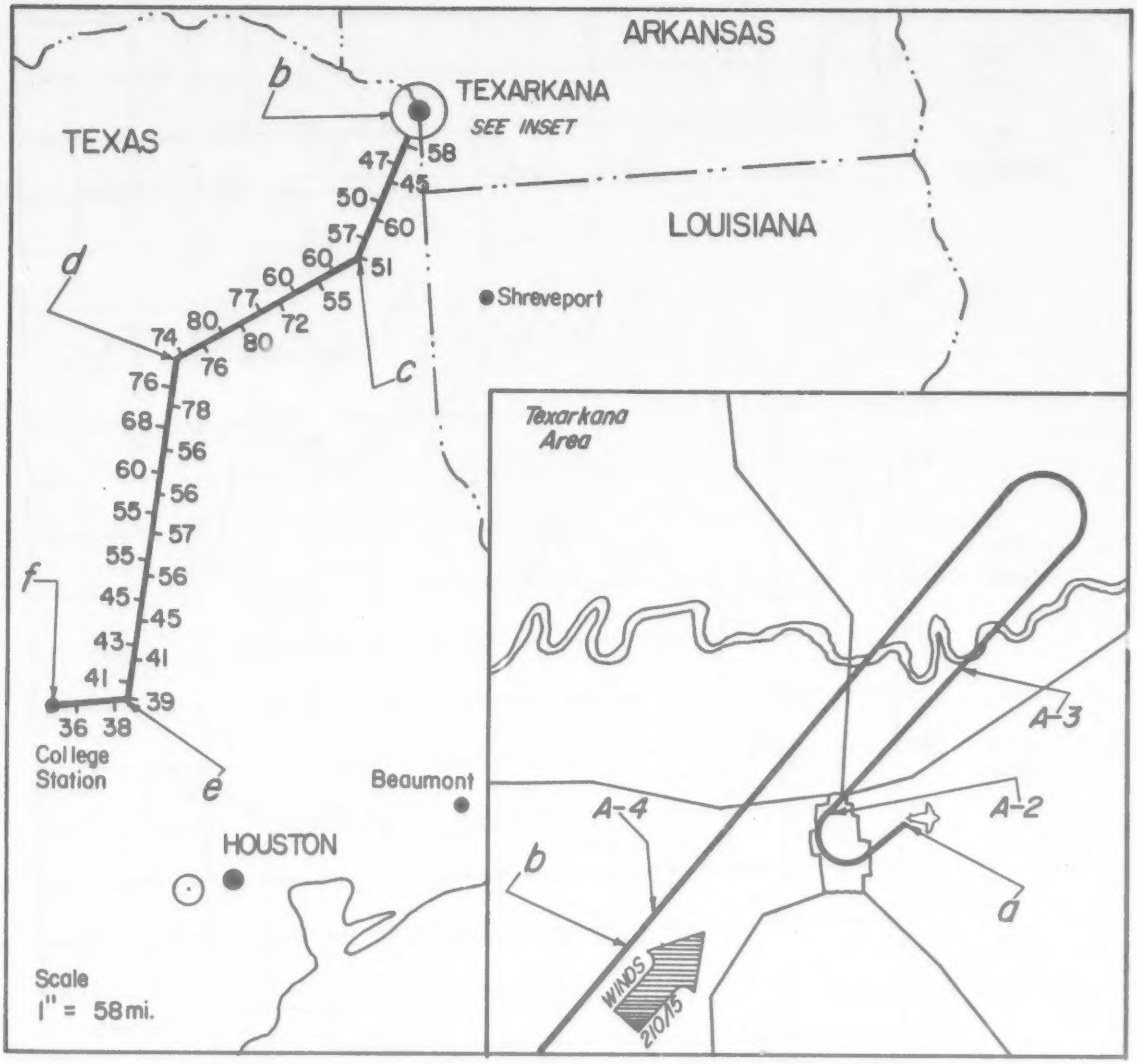

ARKANSAS
TEXAS
TEXARKANA
SEE INSET
LOUISIANA
Shreveport
b
d
c
f
e
47
58
50
45
57
60
60
51
60
55
77
72
80
80
74
76
76
78
68
56
60
56
55
57
55
56
45
45
43
41
41
39
36
38
College Station
Beaumont
HOUSTON
Scale
1" = 58 mi.
Texarkana Area
A-3
A-2
A-4
b
a
WINDS
210/15

Figure B50 Flight #16 on July 15, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 3:35 to 6:10 PM

Leg ab: 3:35 - 3:58 at 1500' MSL
bc: 3:59 - 4:40 at 1500'
cd: 4:41 - 5:40 between 1500' and 3000'
de: 5:41 - 6:01 at 1500'
ef: 6:02 - 6:10 at 1000'

WIND: TKK,210/15

WEATHER: Broken clouds at ~5000' - isolated thunderstorms along route

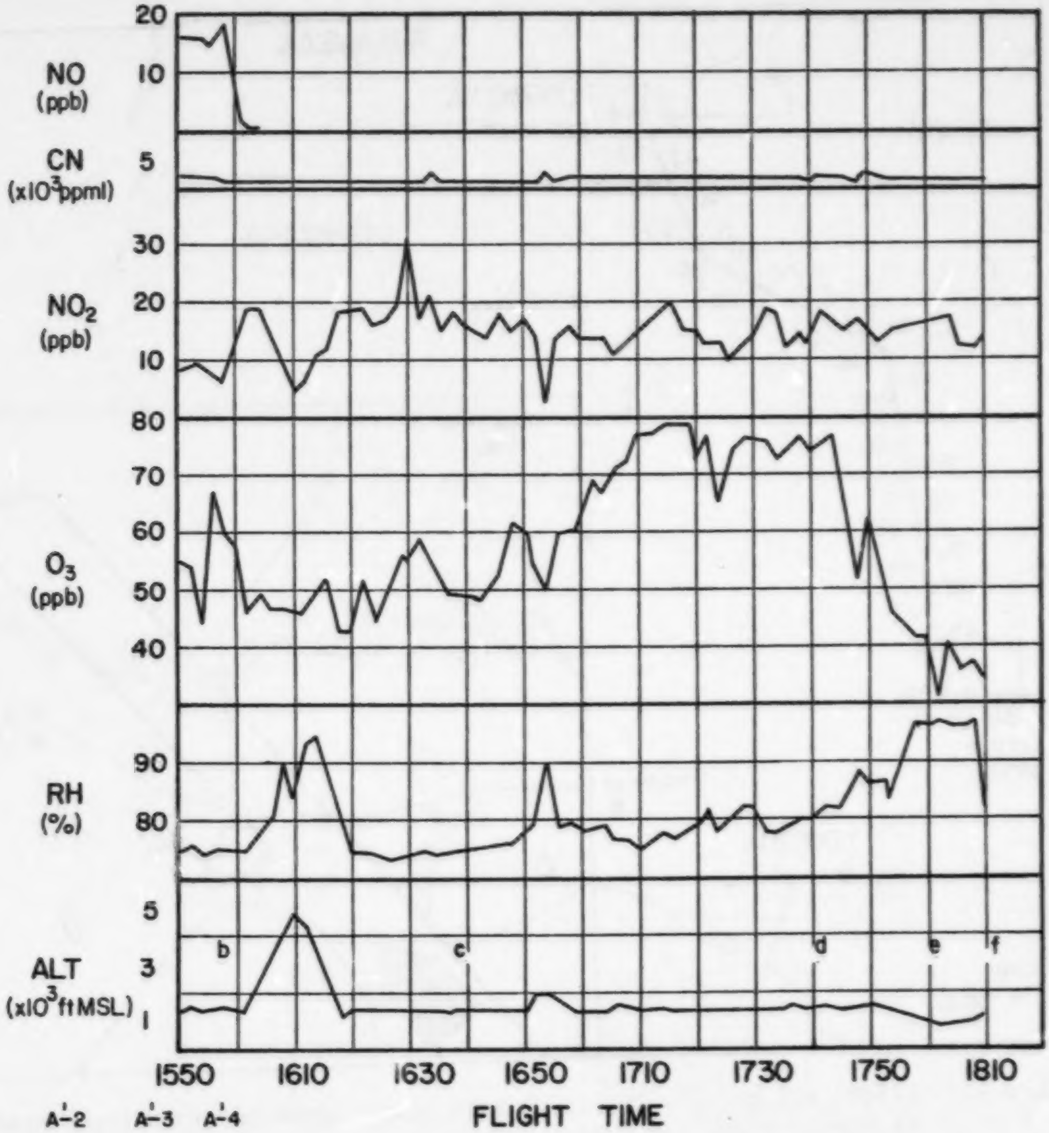


Figure B51 Plot of aircraft data recorded during flight #16 on July 15, 1976.

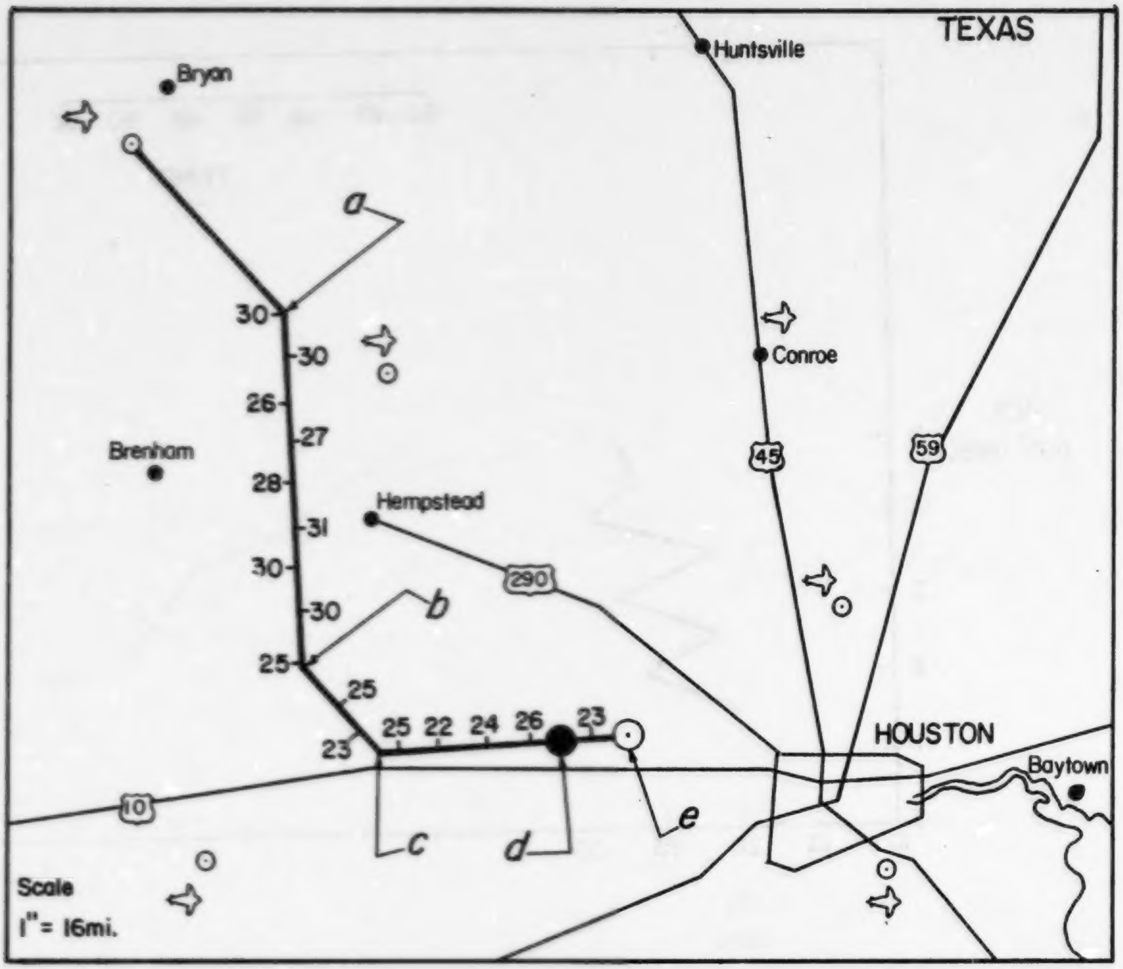

TEXAS
Huntsville
Bryan
Conroe
Brenham
Hempstead
HOUSTON
Baytown
45
59
290
10
a
b
c
d
e
30
30
26
27
28
31
30
30
25
25
23
25
22
24
26
23
Scale
1" = 16mi.

Figure B52 Flight #17 on July 15, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 7:40 - 8:40 PM

Leg
ab: 7:40 - 8:05 at 1500' MSL
bc: 8:06 - 8:13 at 1500'
cd: 8:14 - 8:20 at 1500'
d: 8:21 - 8:29 spiral ascent to 5000'
de: 8:30 - 8:40 slant descent to Lakeside

WIND:

WEATHER: Overcast at ~5000' - isolated thunderstorms enroute

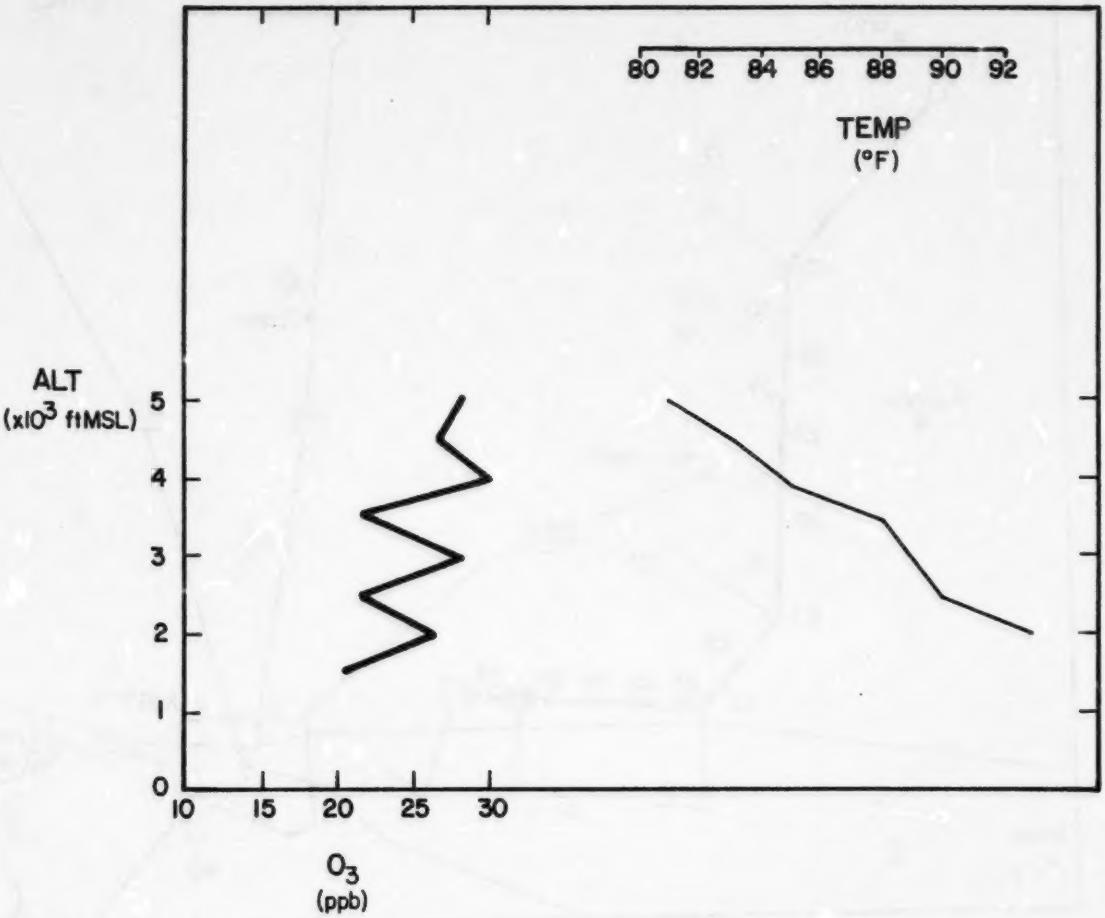


Figure B5 3 Vertical ozone and temperature profiles W of Houston (flt. #17: point d) at 8:25 PM on July 15, 1976.

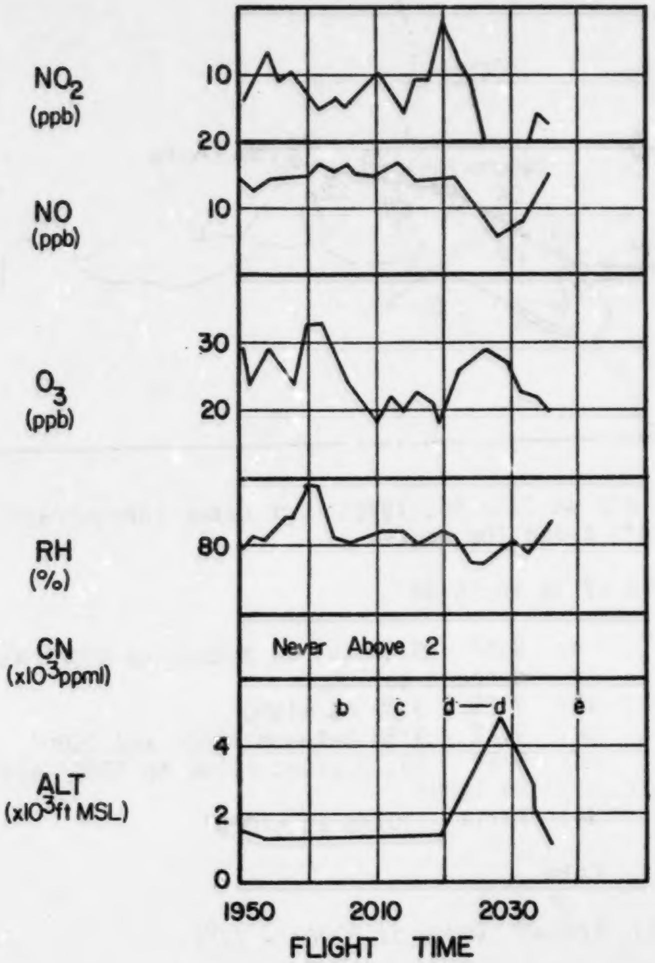


Figure B5 4 Plot of aircraft data recorded during flight #17 on July 15, 1976.

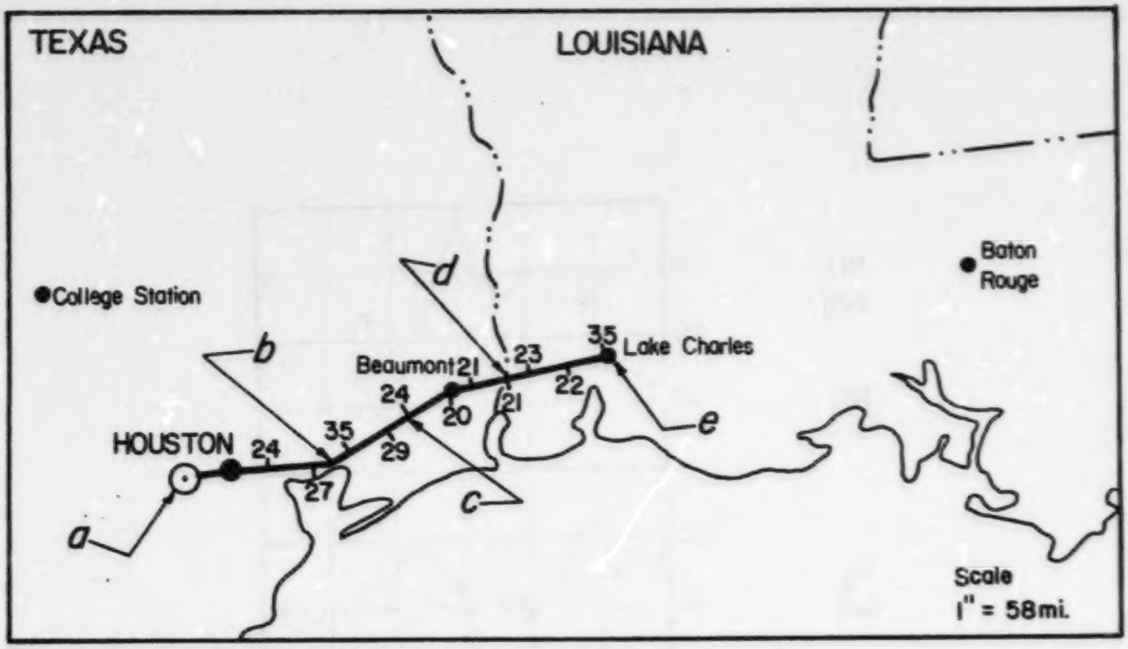

TEXAS
LOUISIANA
College Station
Baton Rouge
b
d
Beaumont
21
23
35
Lake Charles
24
20
21
22
HOUSTON
24
35
29
e
27
c
a
Scale
1" = 58mi.

Figure B55 Flight #18 on July 18, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 8:57 to 10:35 AM

Leg a: 8:57 - 9:24 spiral ascent to 6000' MSL and spiral descent to 1000'
ab: 9:25 - 9:41 at ~1500'
bc: 9:42 - 9:58 between 1000' and 1500'
cd: 9:59 - 10:13 slant climb to 3300' and slant descent to 1000'
de: 10:14 - 10:35 at ~1000'

WIND: Calm

WEATHER: Broken clouds at 8000' - 77^{0}F

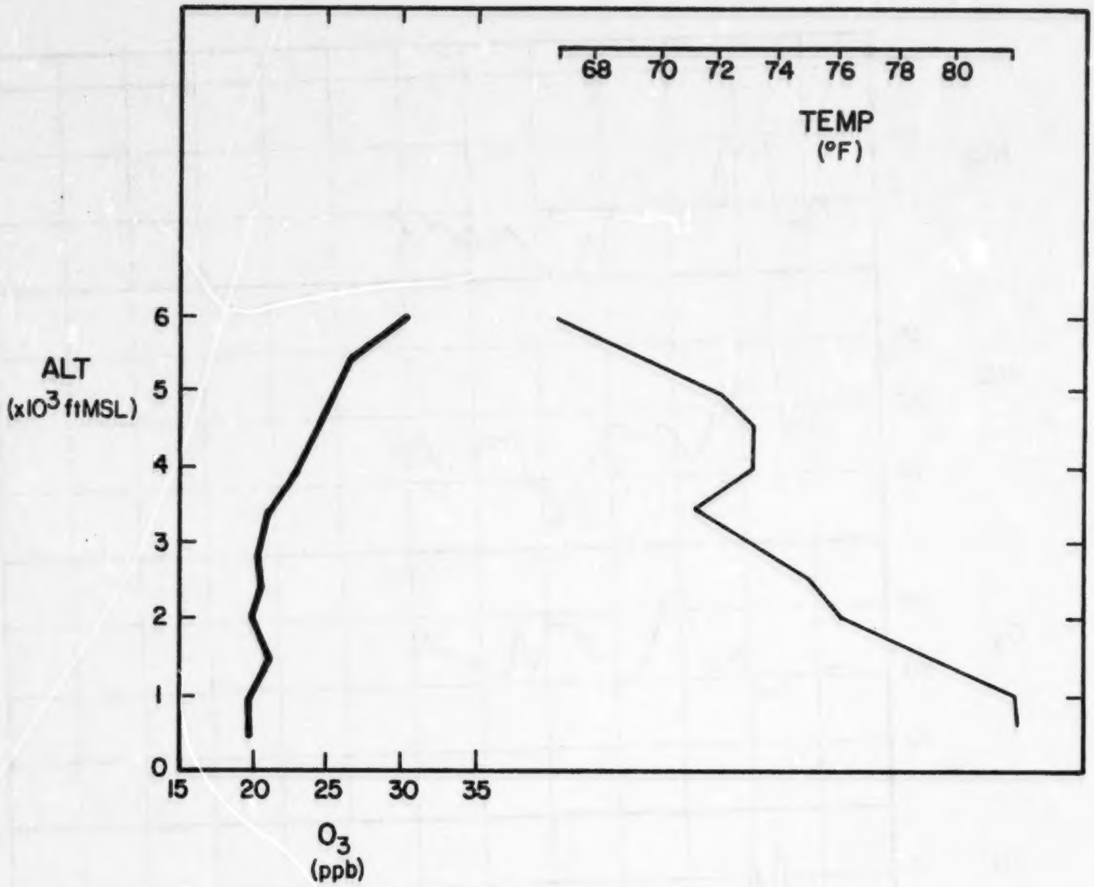


Figure B 56 Vertical ozone and temperature profiles SW of Houston (flt. #18: point a) at 9:10 AM on July 18, 1976

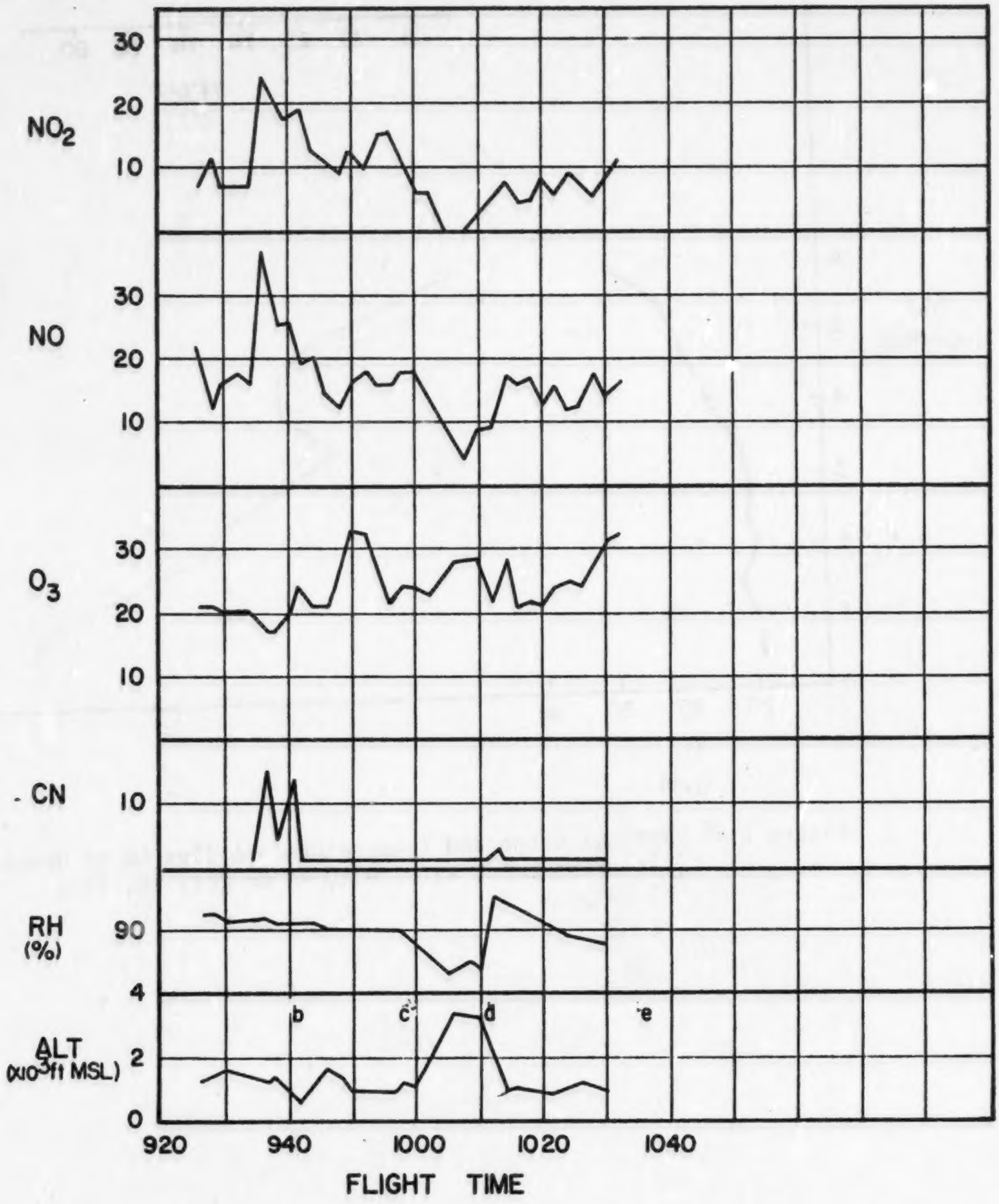


Figure B 57 Plot of aircraft data recorded during flight #18 on July 18, 1976.

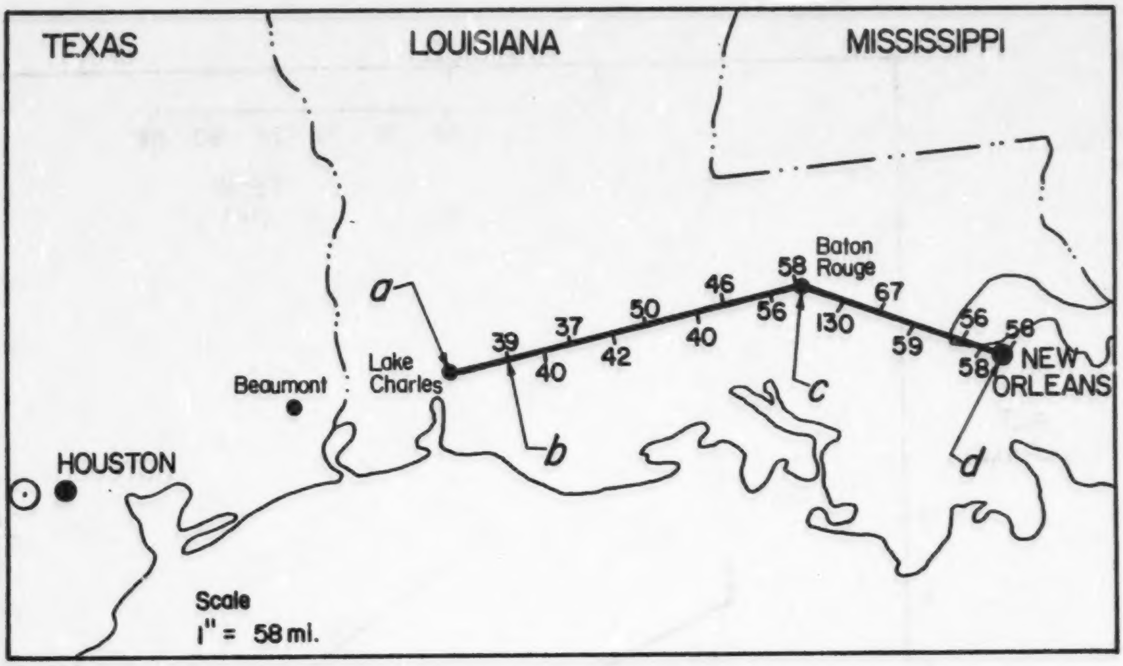

TEXAS
LOUISIANA
MISSISSIPPI
Baton Rouge
58
46
50
37
39
40
42
40
56
130
67
59
56
58
58
NEW ORLEANS
Lake Charles
Beaumont
HOUSTON
a
b
c
d
Scale
1" = 58 mi.

Figure B 58 Flight #19 on July 18, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 11:25 AM to 1:15 PM

Leg
ab: 11:25 - 11:37 slant climb to 4000' MSL
b: 11:38 - 11:44 spiral descent to 1000'
bc: 11:45 - 12:33 at ∿1000'
cd: 12:34 - 1:15 at ∿1000' (climb to 2500' over Baton Rouge then descend to 1000')

WIND: Calm

WEATHER: Clear and warm

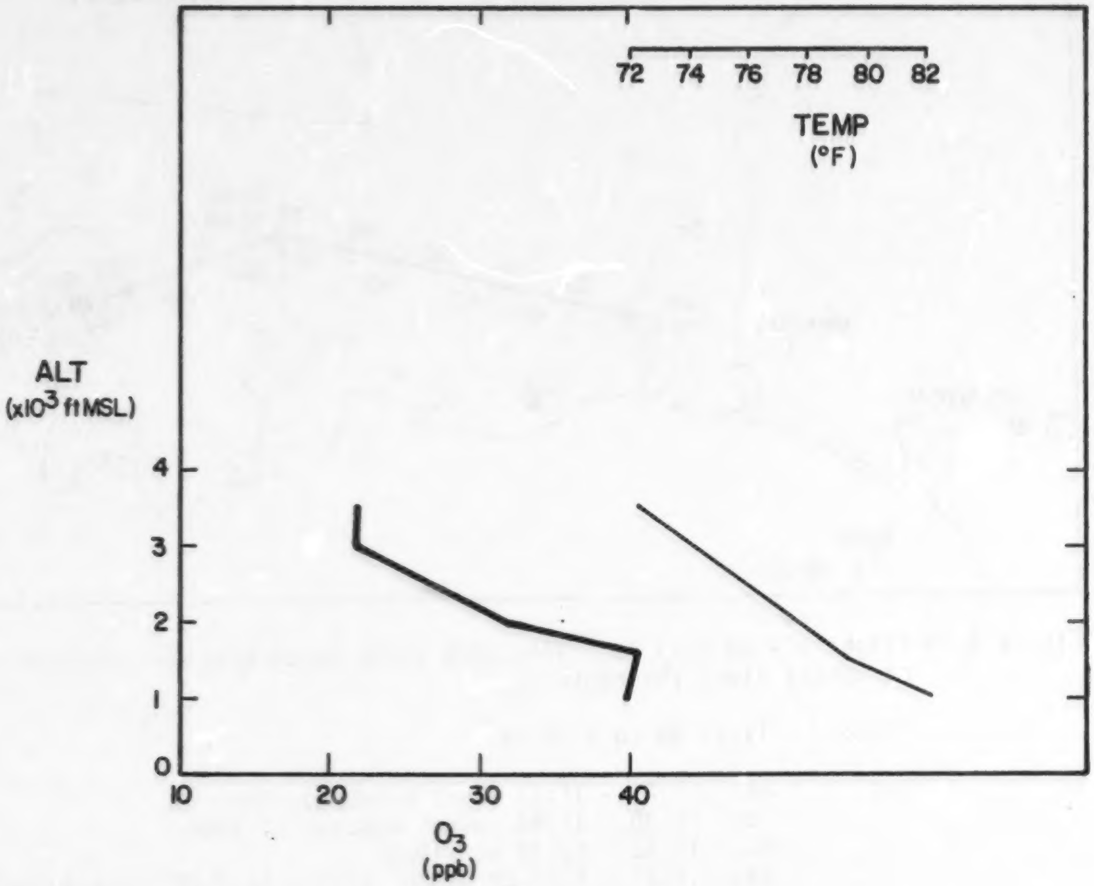


Figure B 59 Vertical ozone and temperature profiles near Lake Charles, LA, (flt. #19: point b) at 11:40 AM on July 18, 1976.

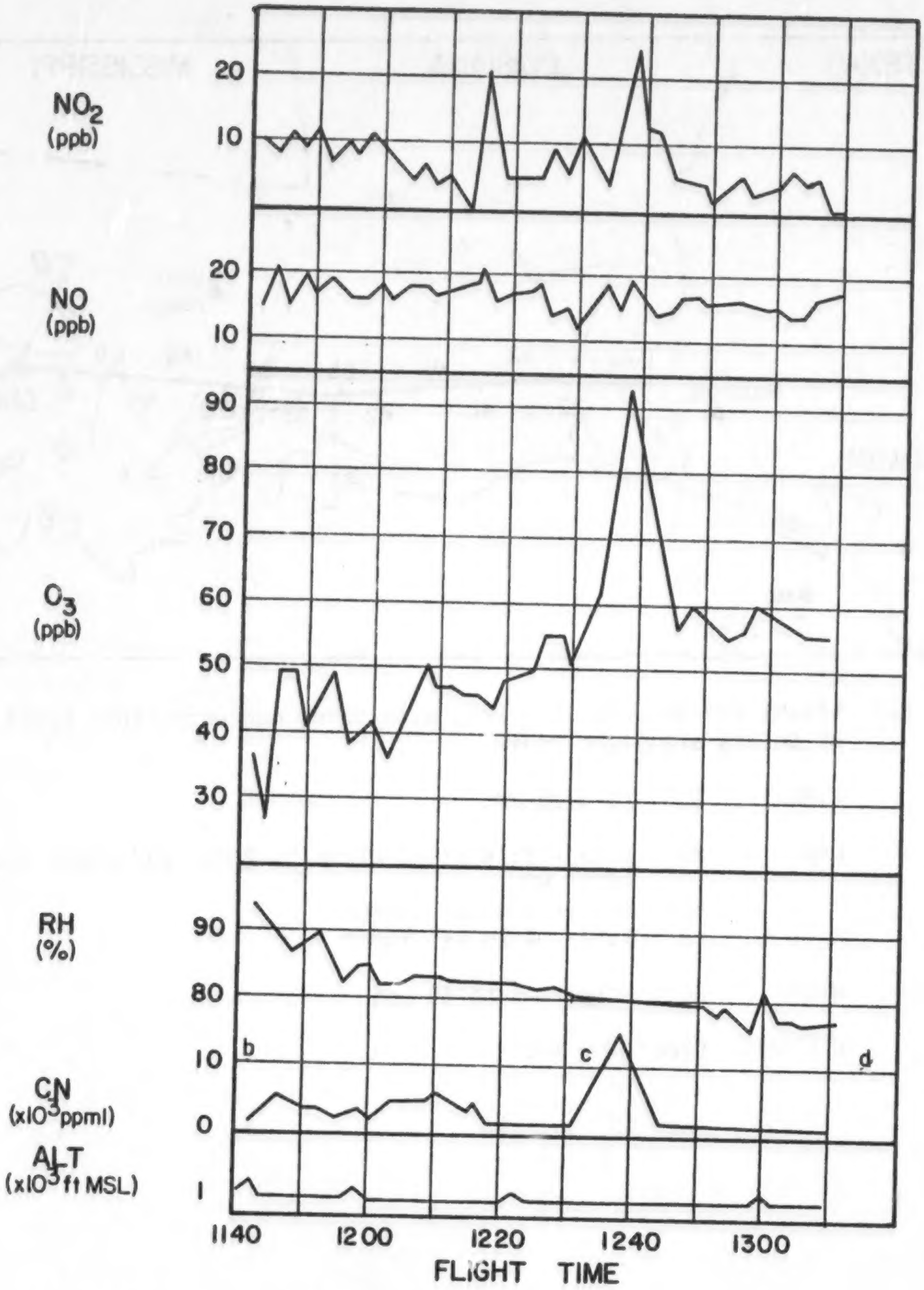


Figure B60 Plot of aircraft data recorded during flight #19 on July 18, 1976.

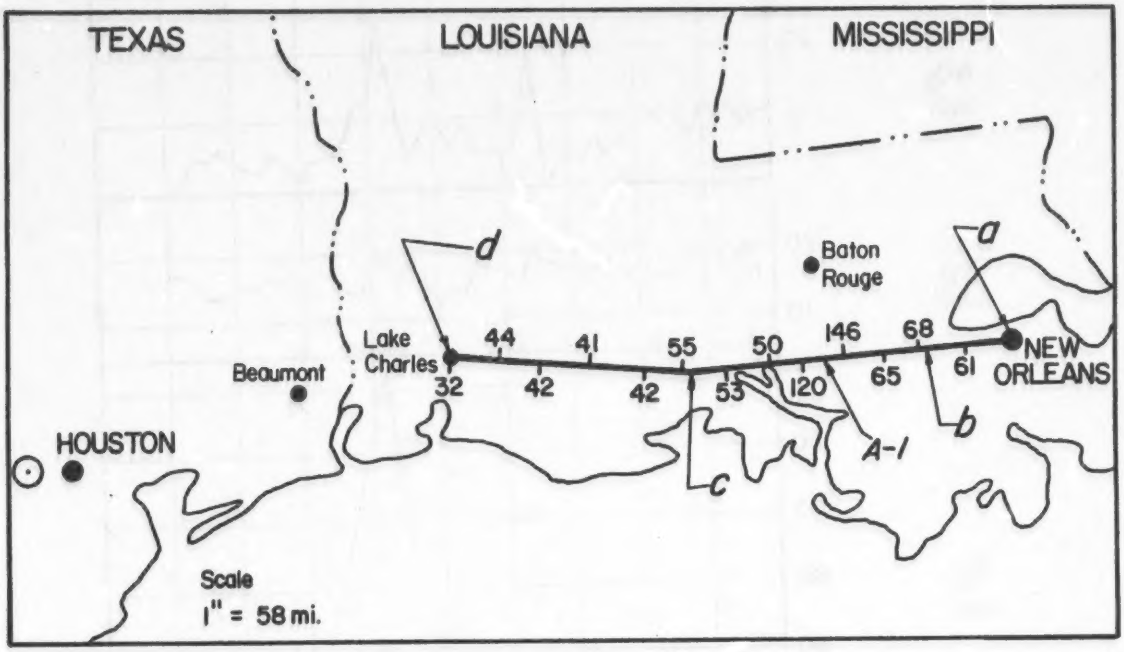

TEXAS
LOUISIANA
MISSISSIPPI
d
a
Baton Rouge
Lake Charles
44
41
55
50
146
68
NEW ORLEANS
Beaumont
32
42
42
53
120
65
61
b
A-1
HOUSTON
c
Scale
1" = 58 mi.

Figure B61 Flight #20 on July 18, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 2:53 to 4:25 PM

Leg ab: 2:53 - 3:14 slant climb to 2500' and slant descent to 1000' MSL
bc: 3:15 - 3:51 at ∿1000'
cd: 3:52 - 4:20 at ∿1000'

WIND: Northerly at 5 to 10 mph

WEATHER: Clear and hot

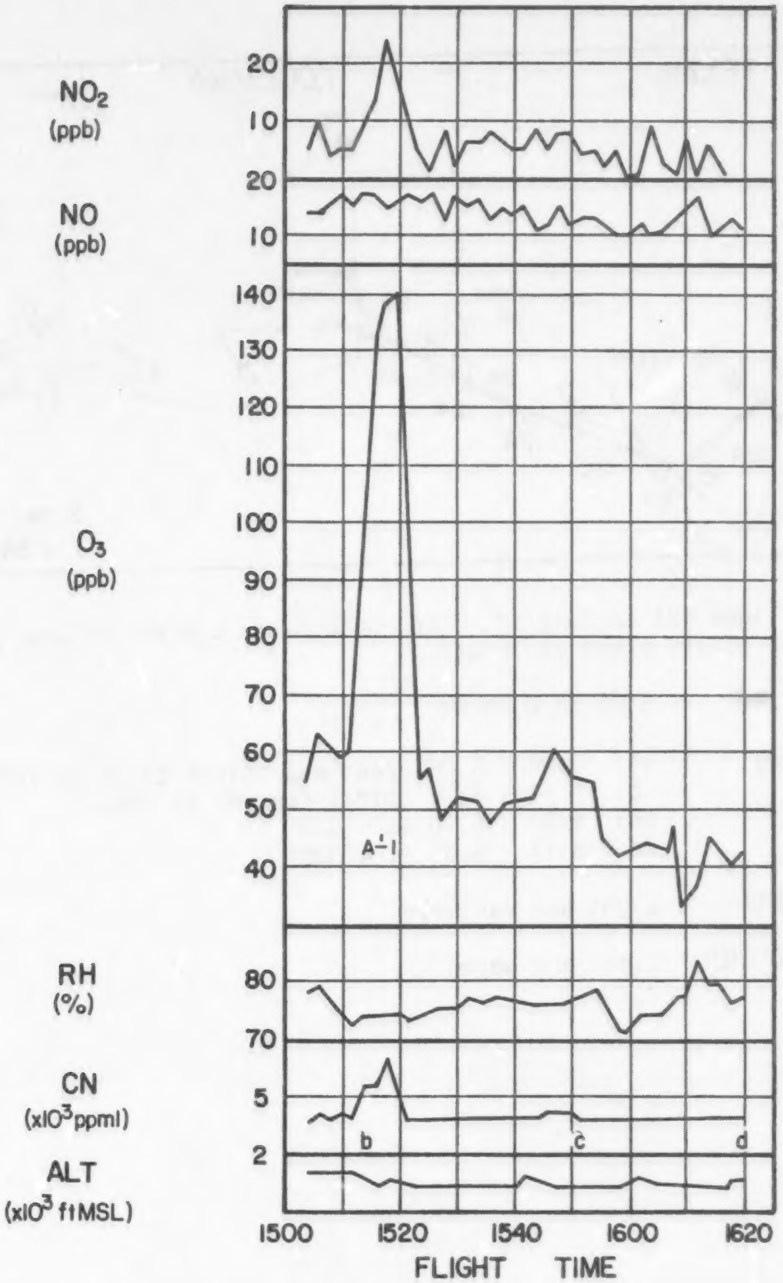


Figure B62 Plot of aircraft data recorded during flight #20 on July 18, 1976.

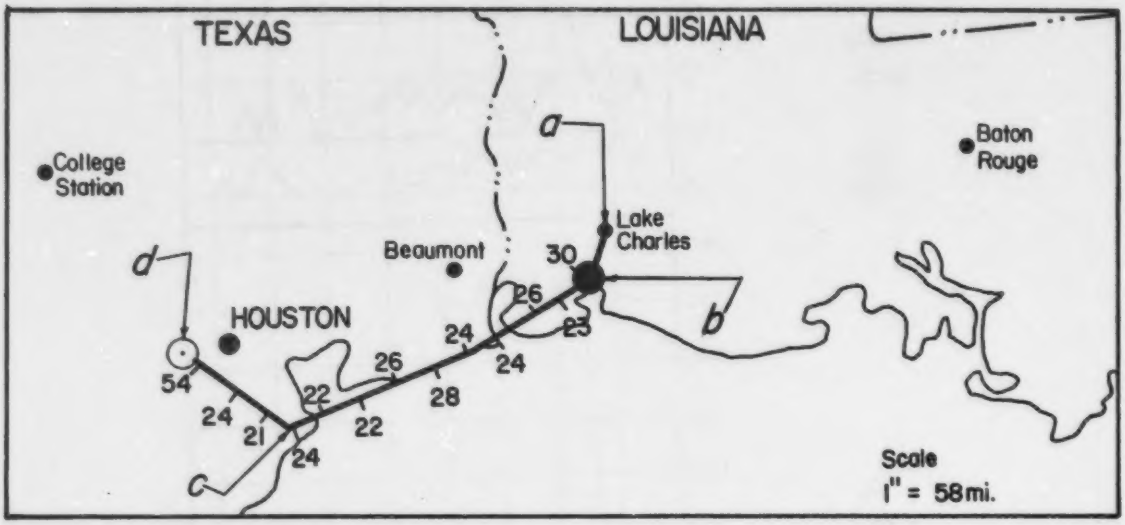

TEXAS
LOUISIANA
a
Baton Rouge
College Station
Lake Charles
d
Beaumont
30
HOUSTON
26
b
24
23
26
24
54
22
28
24
21
22
24
c
Scale
1" = 58mi.

Figure B63 Flight #21 on July 18, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 5:00 to 6:40 PM

Leg
ab: 5:00 - 5:09 slant and spiral climb to 7000' MSL
b: 5:10 - 5:26 spiral descent to 1000'
bc: 5:27 - 6:10 at ∿1000'
cd: 6:11 - 6:35 at ∿1000'

WIND: Light and variable

WEATHER: Clear and warm

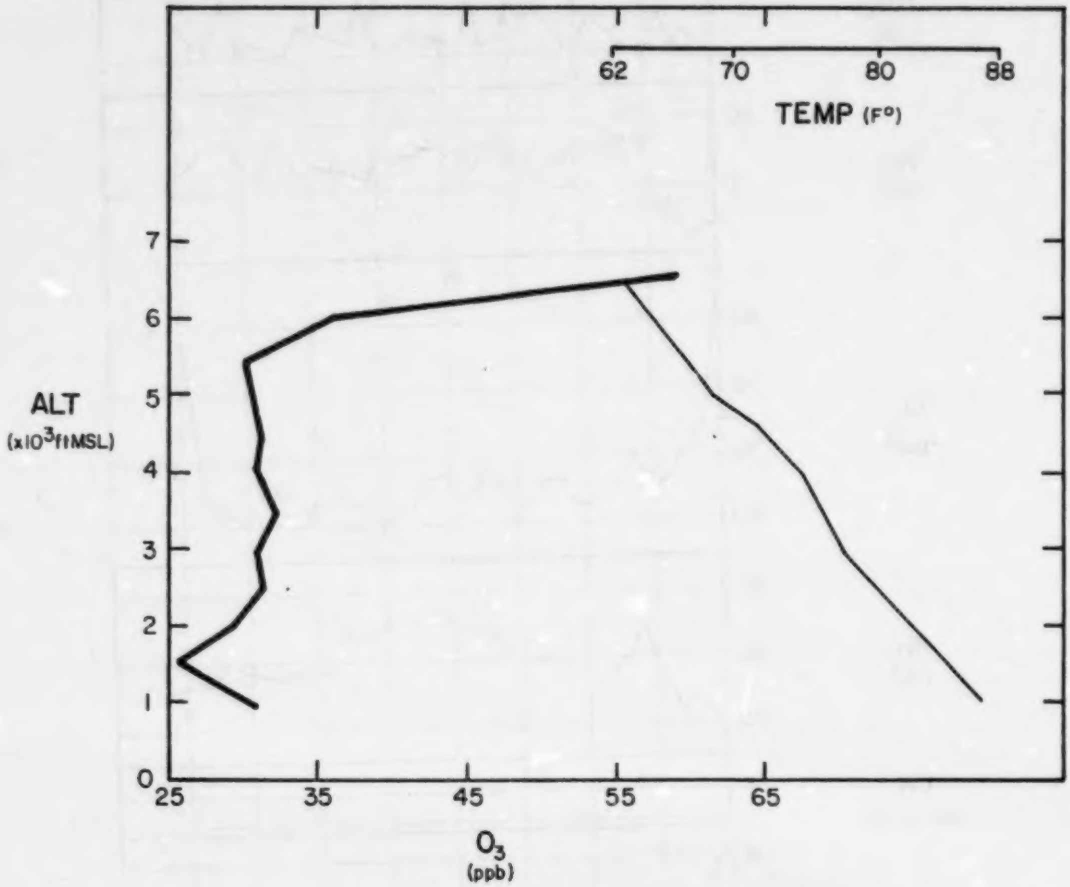


Figure B64. Vertical ozone and temperature profiles South of Lk. Charles, LA. (Flight #21: point b) at 5:10 pm on July 18, 1976.

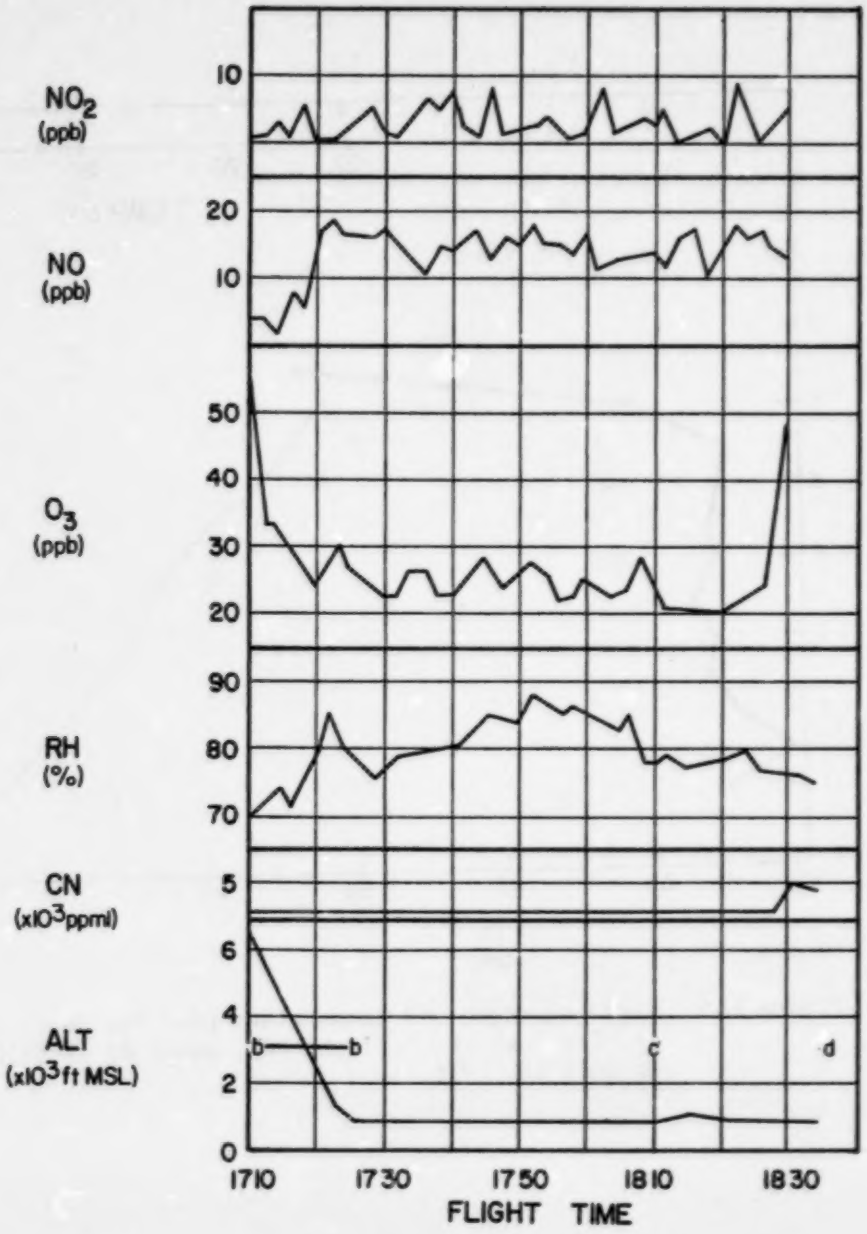


Figure B65 Plot of aircraft data recorded during flight #21 on July 18, 1976.

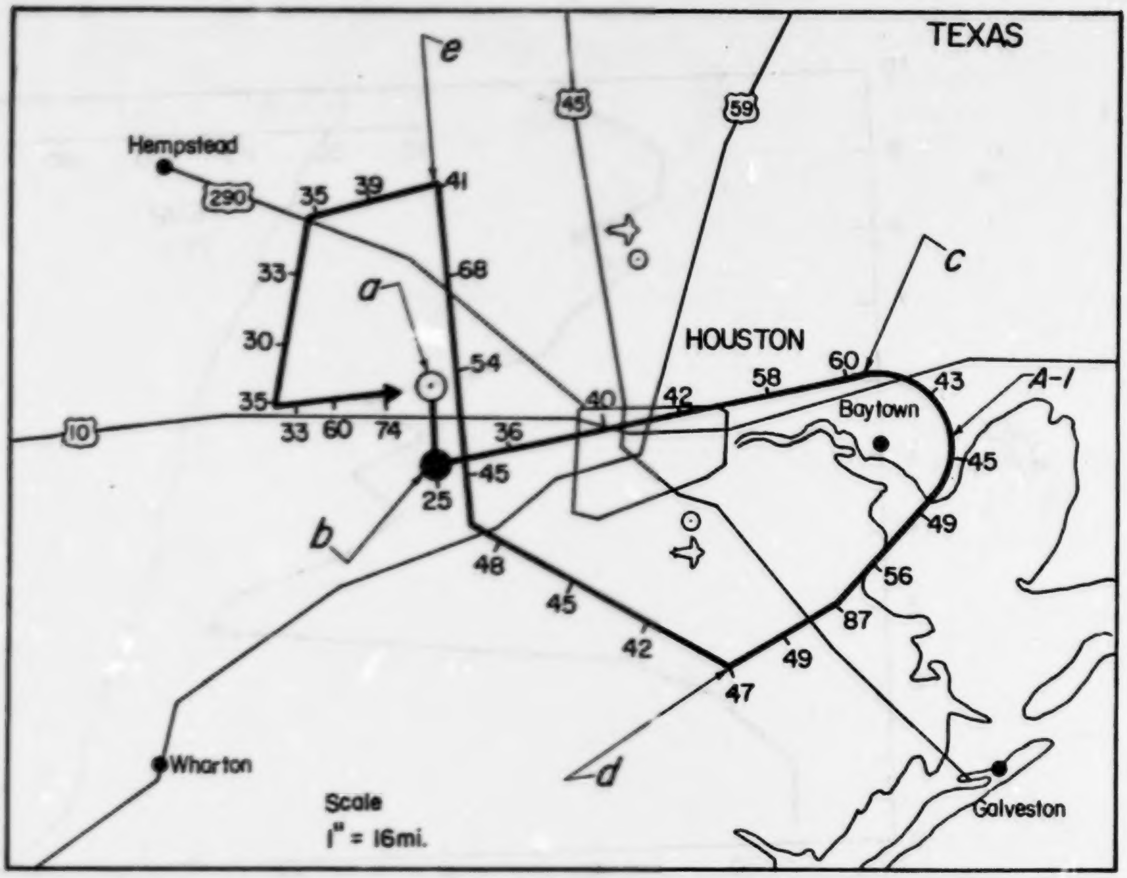

TEXAS
HOUSTON
Hempstead
Baytown
Wharton
Galveston
290
45
59
10
a
b
c
d
e
A-1
35
39
41
33
30
35
33
60
74
68
54
36
45
25
40
42
58
60
43
45
49
56
87
49
47
42
45
48
Scale
1" = 16mi.

Figure B66 Flight #22 on July 20, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 9:03 to 11:10 AM

Leg
ab: 9:03 - 9:21 slant and spiral climb to 10,000' MSL
b: 9:22 - 9:43 spiral descent to 150'
bc: 9:44 - 10:04 at ~800'
cd: 10:05 - 10:22 at ~800'
de: 10:23 - 10:45 at ~800'
ea: 10:46 - 11:10 at ~800'

WIND: IAH,050/3 HUB,120/3

WEATHER: Clear - 6 miles visibility in haze and smoke - 81°F

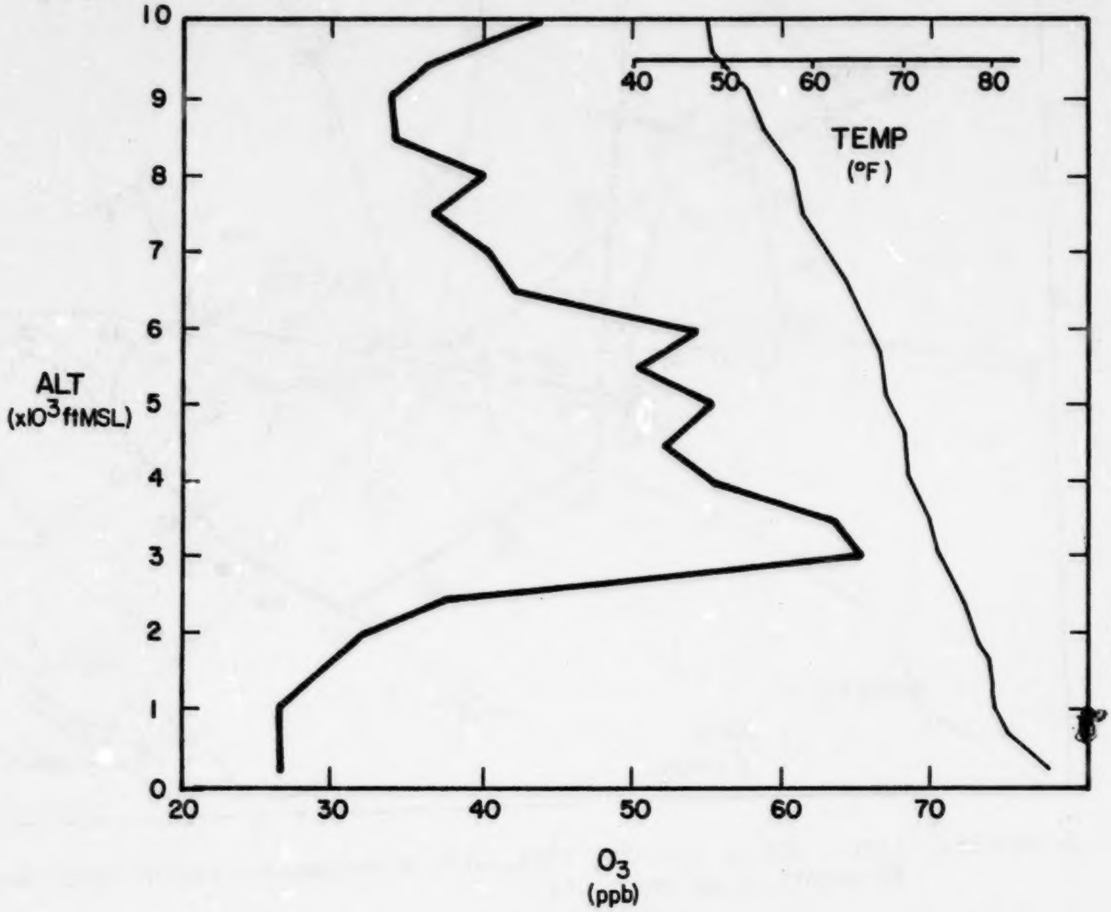


Figure B67 Vertical ozone and temperature profiles SW of Houston (flt. #22: point b) at 9:30 AM on July 20, 1976.

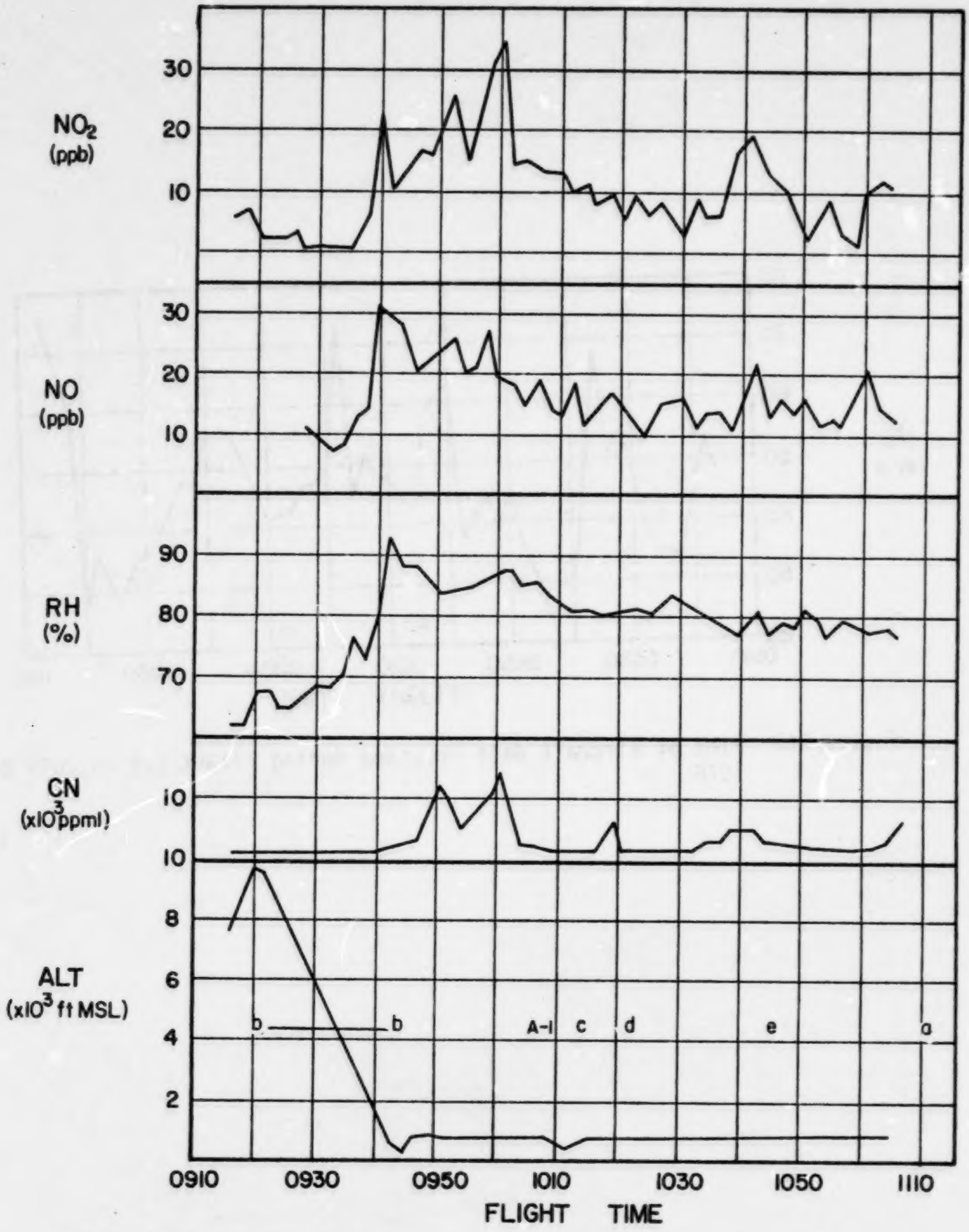


Figure B 68 Plot of aircraft data recorded during flight #22 on July 20, 1976.

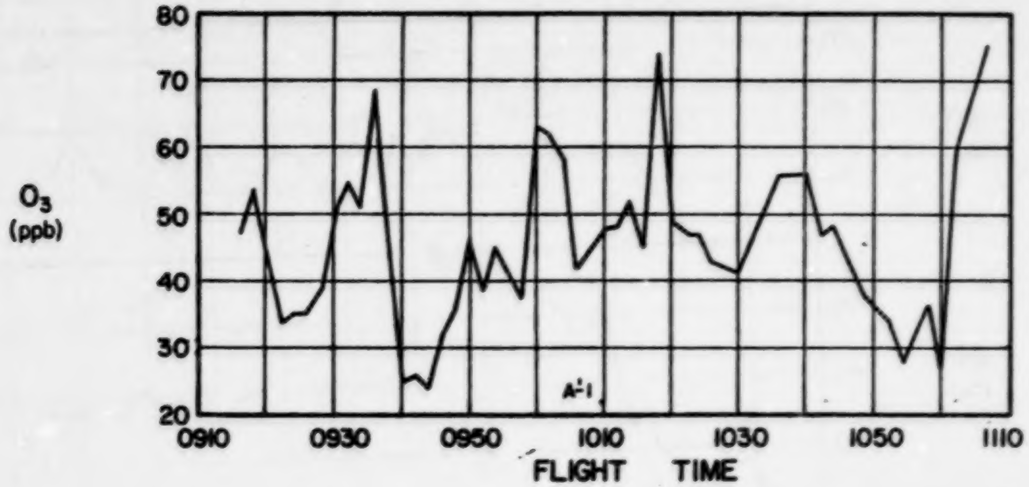


Figure B68 Plot of aircraft data recorded during flight #22 on July 20, 1976.

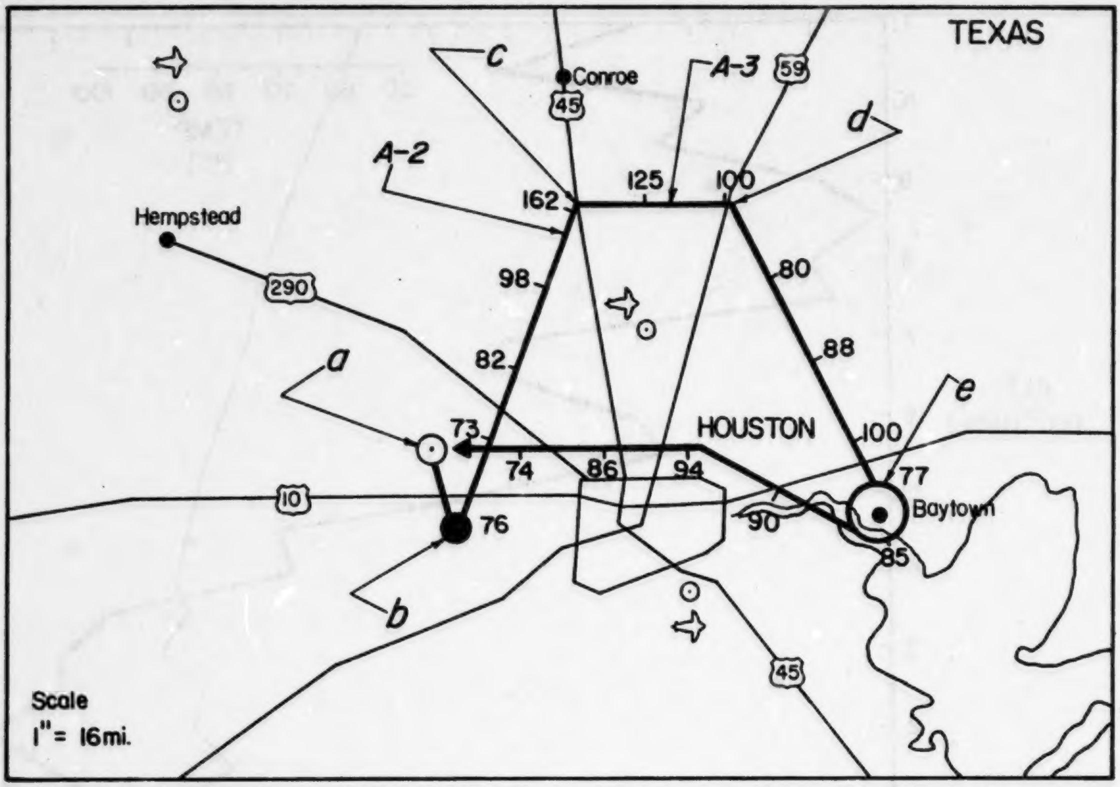

TEXAS
C
Conroe
45
A-3
59
d
A-2
162
125
100
Hempstead
290
98
80
82
88
a
e
73
HOUSTON
100
74
86
94
77
10
Baytown
76
90
85
b
45
Scale
1" = 16mi.

Figure B69 Flight #23 on July 20, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 5:12 to 7:15 PM

Leg
ab: 5:12 - 5:39 slant and spiral climb to 12,000' MSL
b: 5:40 - 6:07 spiral descent to 200' and climb to 1400'
bc: 6:08 - 6:18 at ∿1400'
cd: 6:19 - 6:29 at ∿1400'
de: 6:30 - 6:39 at ∿1400'
e: 6:40 - 6:50 2 mile, 520° arc of refinery at ∿1400'
ea: 6:51 - 7:10 at ∿1400'

WIND: IAH,170/9 HUB,160/14

WEATHER: A few scattered clouds - good visibility - 97°F

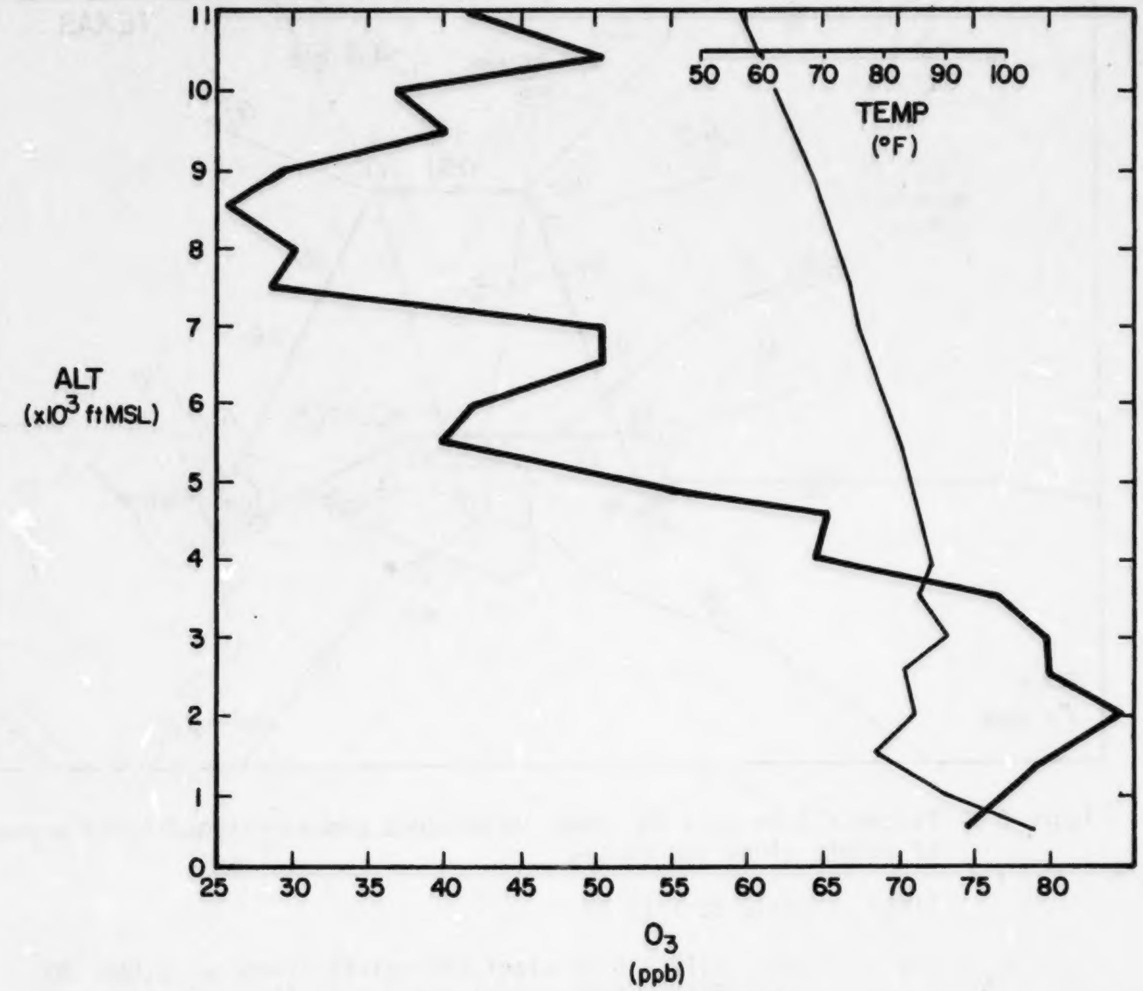


Figure B70 Vertical ozone and temperature profiles W of Houston (flt. #23: point b) at 5:40 PM on July 20, 1976.

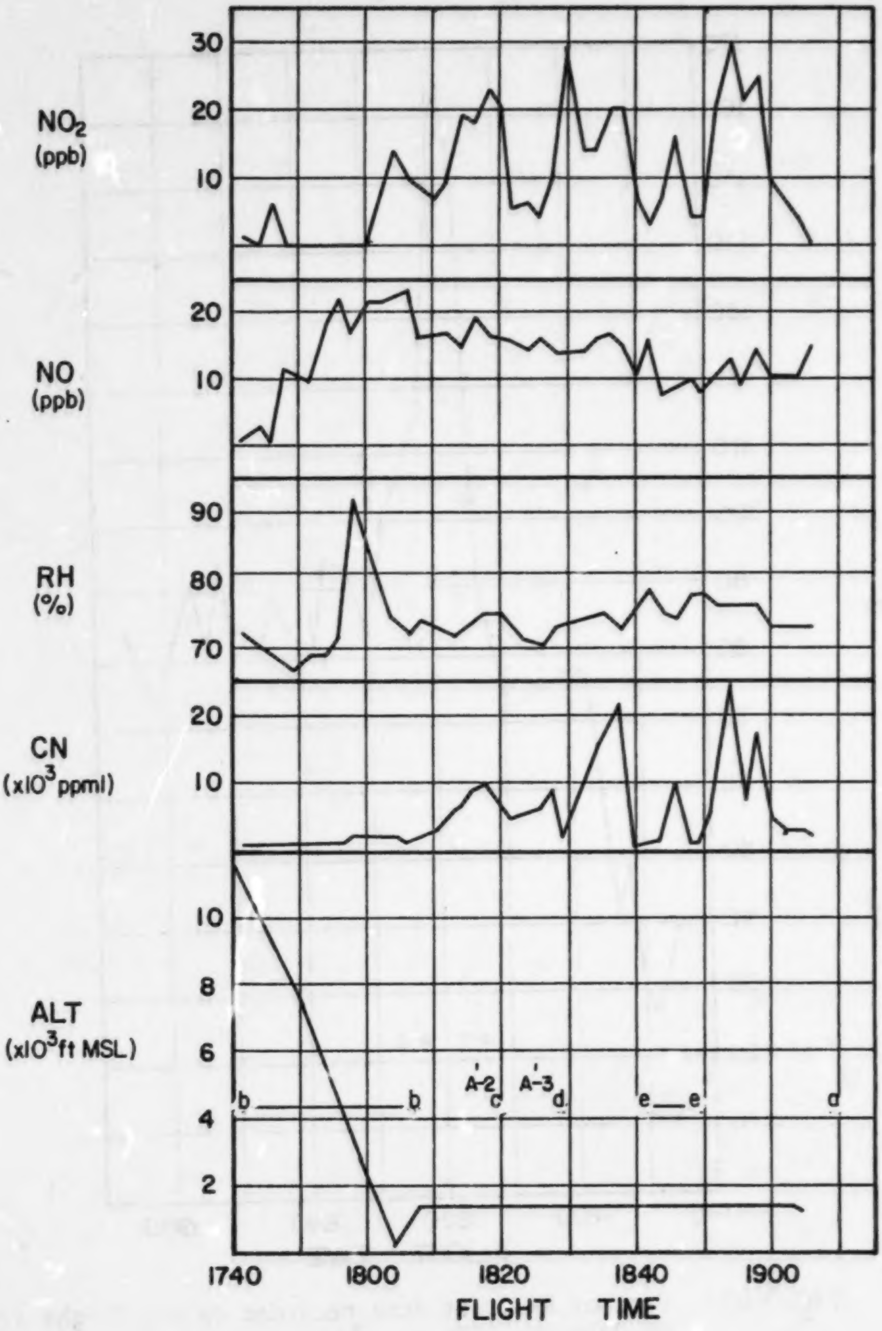


Figure B71 Plot of aircraft data recorded during flight #23 on July 20, 1976.

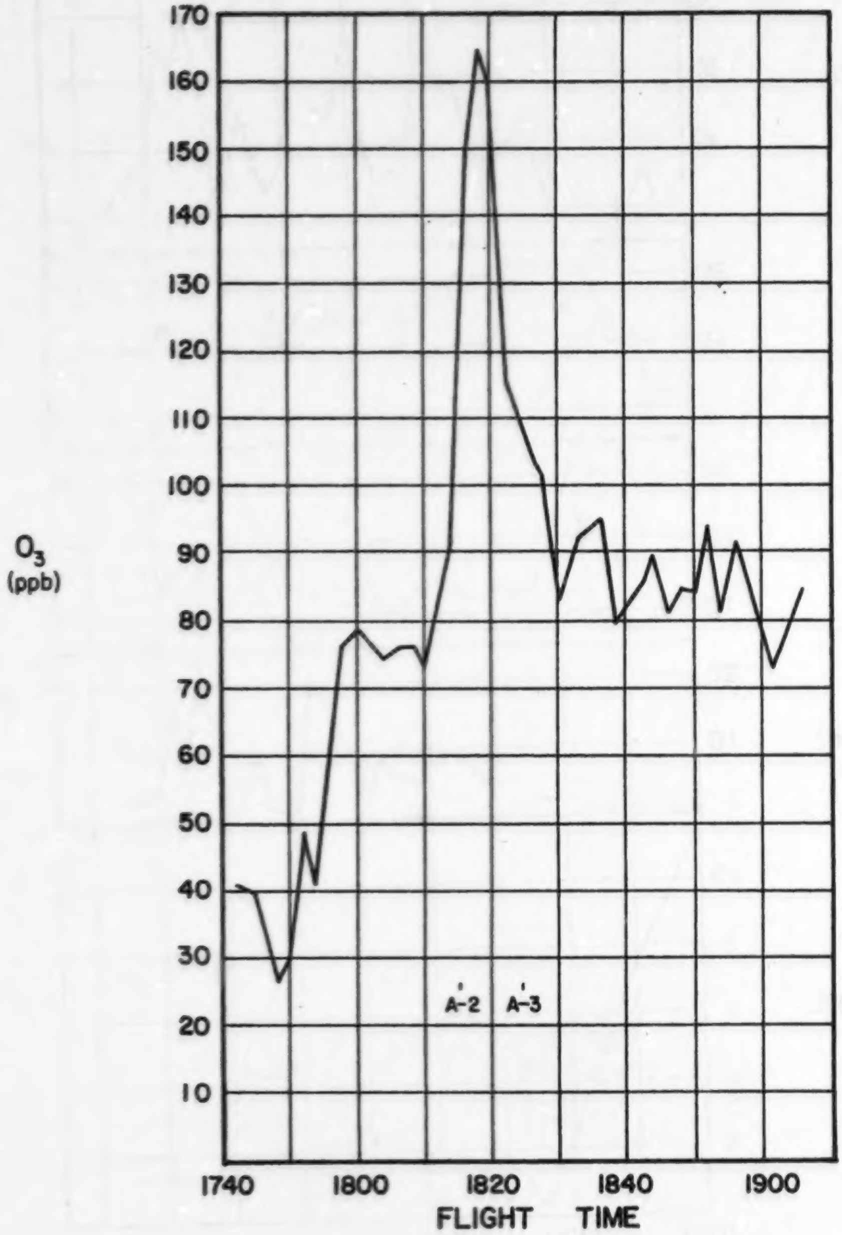


Figure B7 1 Plot of aircraft data recorded during flight #23 on July 20, 1976.

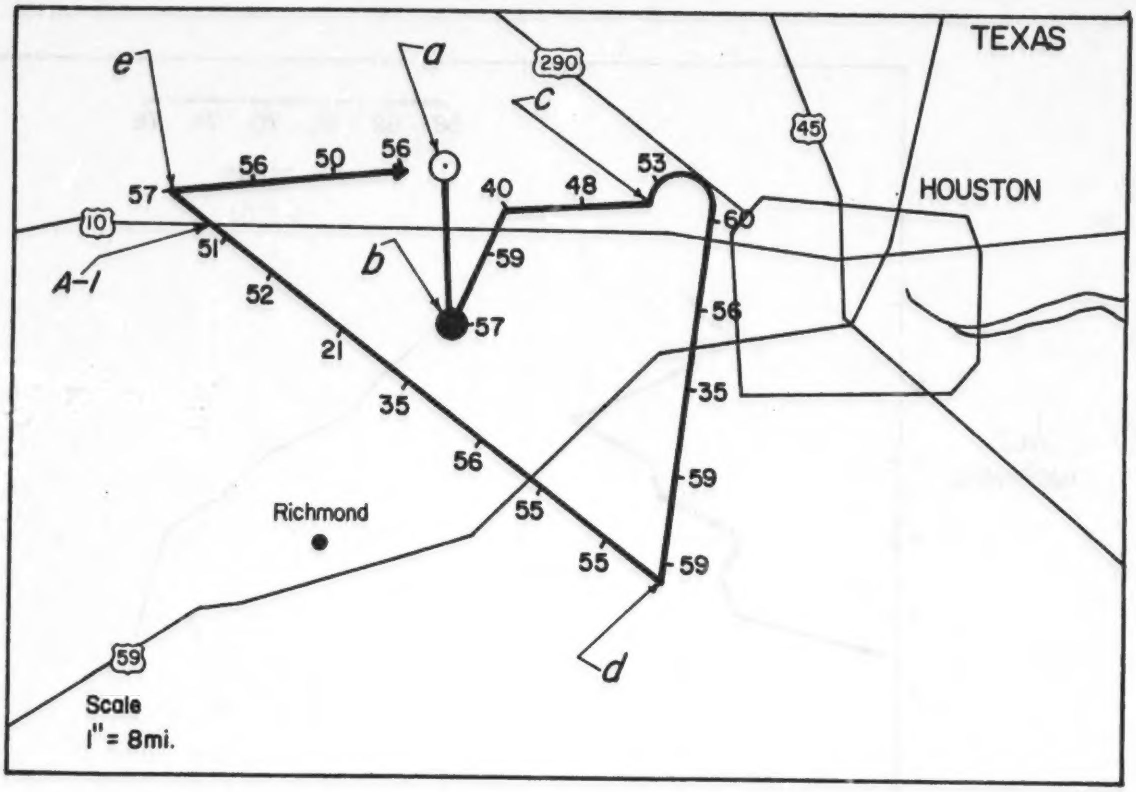

TEXAS
HOUSTON
Richmond
290
45
10
59
a
b
c
d
e
A-1
57
56
50
56
40
48
53
60
59
57
51
52
21
35
56
55
55
59
59
35
56
Scale
1" = 8mi.

Figure B72 Flight #24 on July 21, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 7:55 to 9:15 AM

Leg
ab: 7:55 - 8:07 slant and spiral climb to 7000' MSL
b: 8:08 - 8:26 spiral descent to 200' and climb to 1000'
bc: 8:27 - 8:42 at 1000'
cd: 8:43 - 8:49 at 1000'
de: 8:50 - 9:01 at ~1000'
ea: 9:02 - 9:15 at ~1000'

WIND: IAH,calm HUB,030/4

WEATHER: High broken clouds - 4 miles visibility in fog, haze and smoke - isolated thunderstorms - 71°F

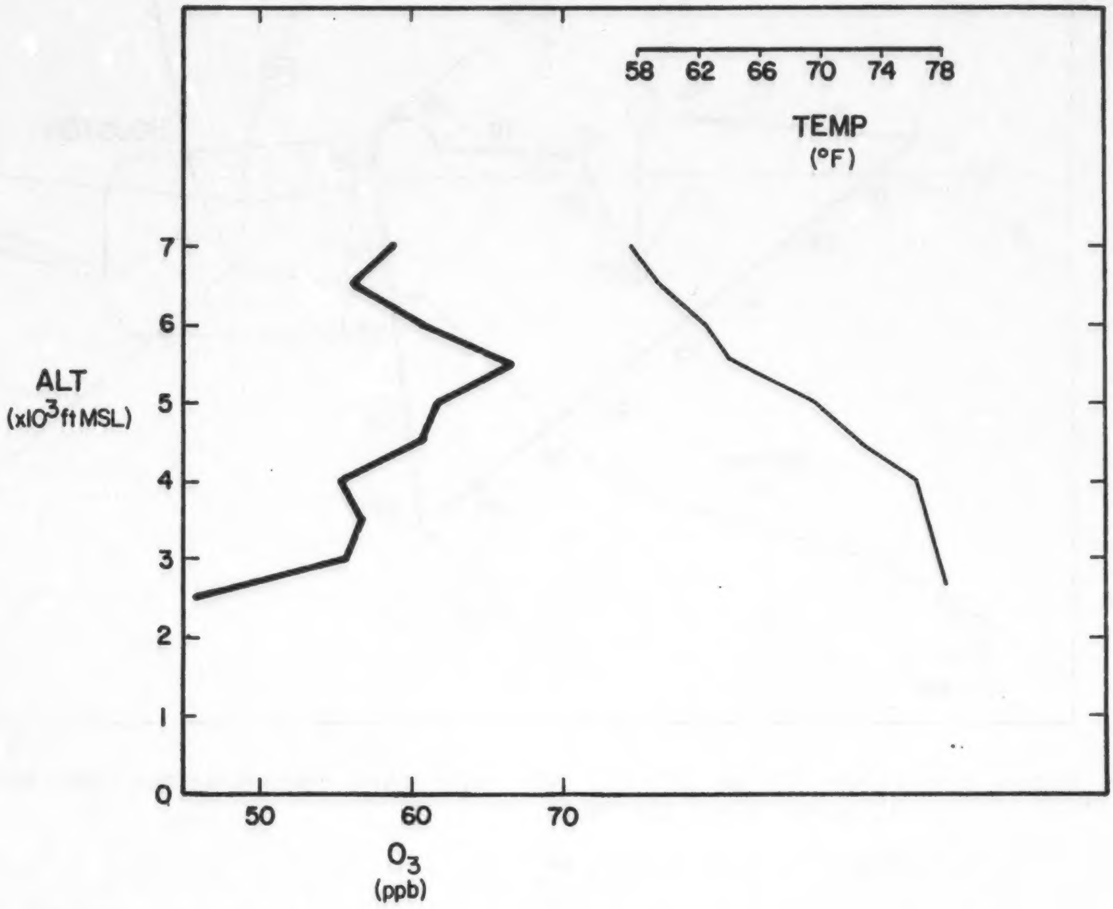


Figure B73 Vertical ozone and temperature profiles W of Houston (flt. #24: point b) at 8:15 AM on July 21, 1976.

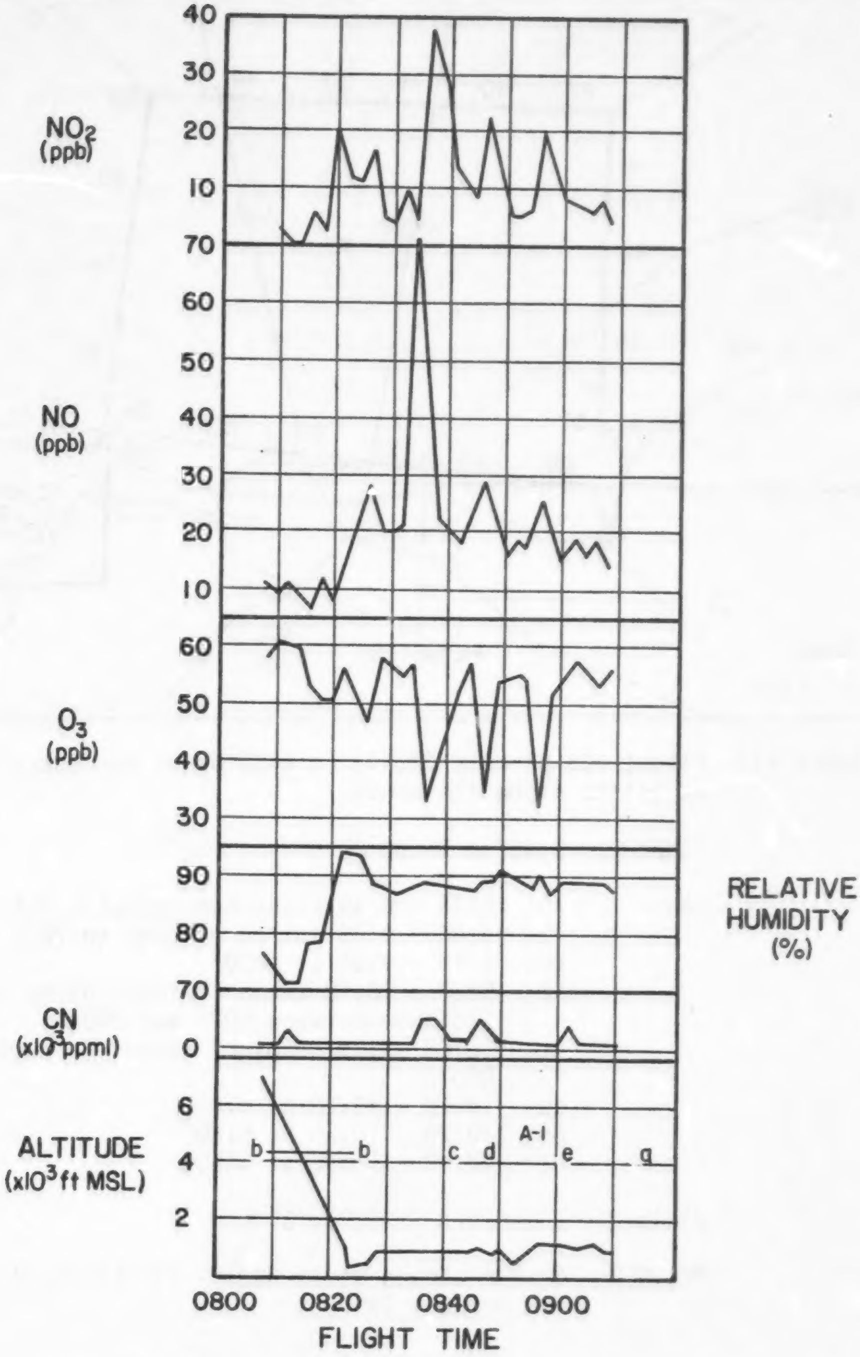


Figure B74 Plot of aircraft data recorded during flight #24 on July 21, 1976.

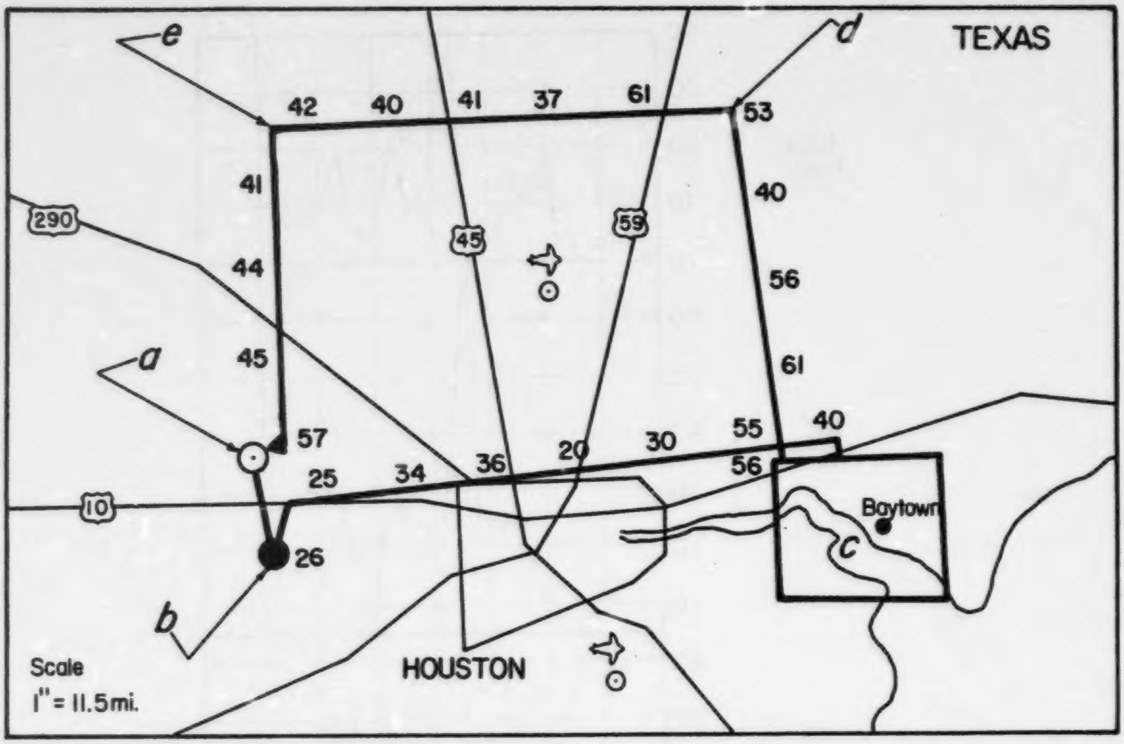

e
d
TEXAS
42
40
41
37
61
53
41
290
45
59
40
44
56
a
45
61
57
55
40
25
34
36
20
30
56
10
Baytown
c
26
b
Scale
1" = 11.5mi.
HOUSTON

Figure B75 Flight #25 on July 22, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 8:45 to 10:50 AM

Leg
ab: 8:45 - 8:59 slant and spiral climb to 8000' MSL
b: 9:00 - 9:18 spiral descent to 200'
bc: 9:19 - 9:36 at 1000'
c: 9:37 - 10:18 Exxon refinery plume investigation, altitude between 500' and 3000'
c: 10:08 - 10:16 spiral ascent to 3000' and descent to 200'
cd: 10:19 - 10:28 at ~1000'
de: 10:29 - 10:39 at ~1500'
ea: 10:40 - 10:50 at ~1500'

WIND: IAH,060/5 HUB,030/3

WEATHER: Broken clouds at 10,000' - visibility 4 miles in fog and smoke - 79°F

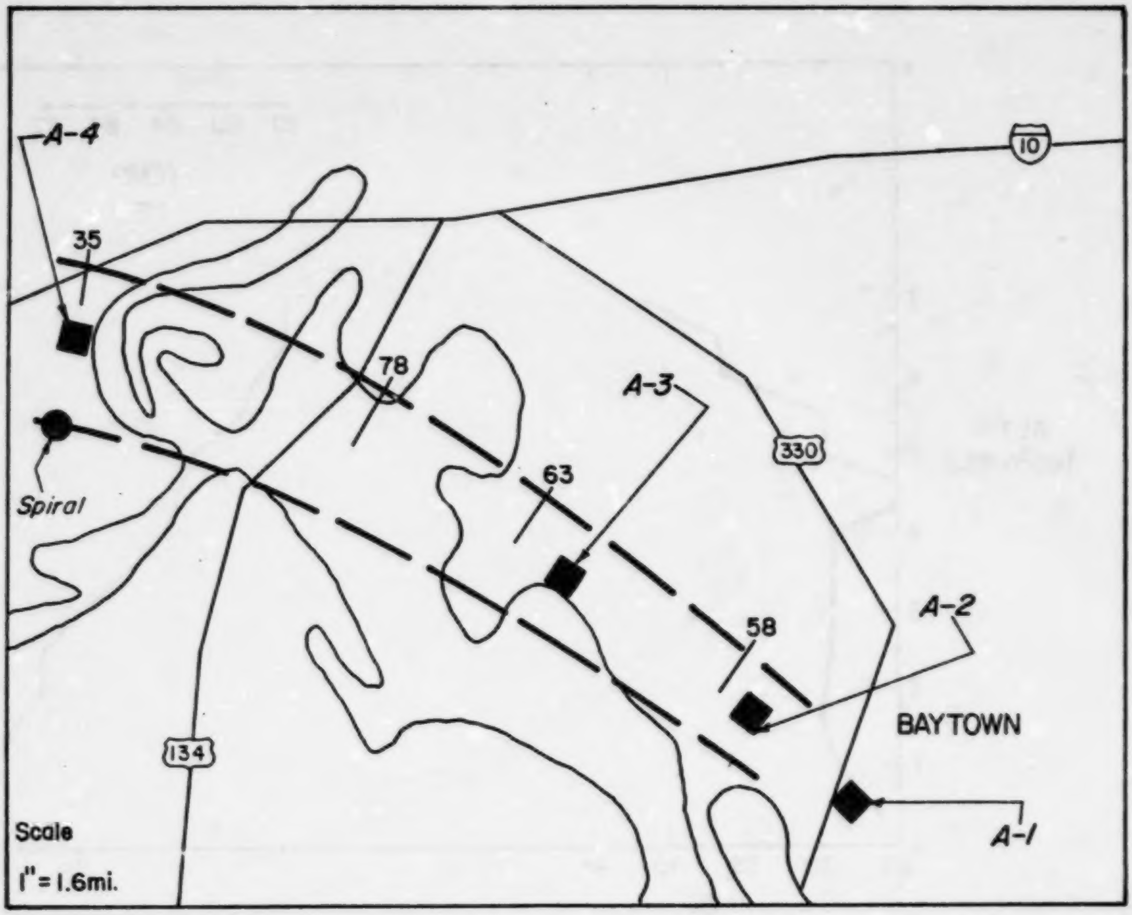

A-4
10
35
78
A-3
330
63
Spiral
A-2
58
BAYTOWN
134
A-1
Scale
1" = 1.6mi.

Figure B75 Flight #25 on July 22, 1976, continued.

- - - - - - - - - - Probable refinery plume and area of highest ozone

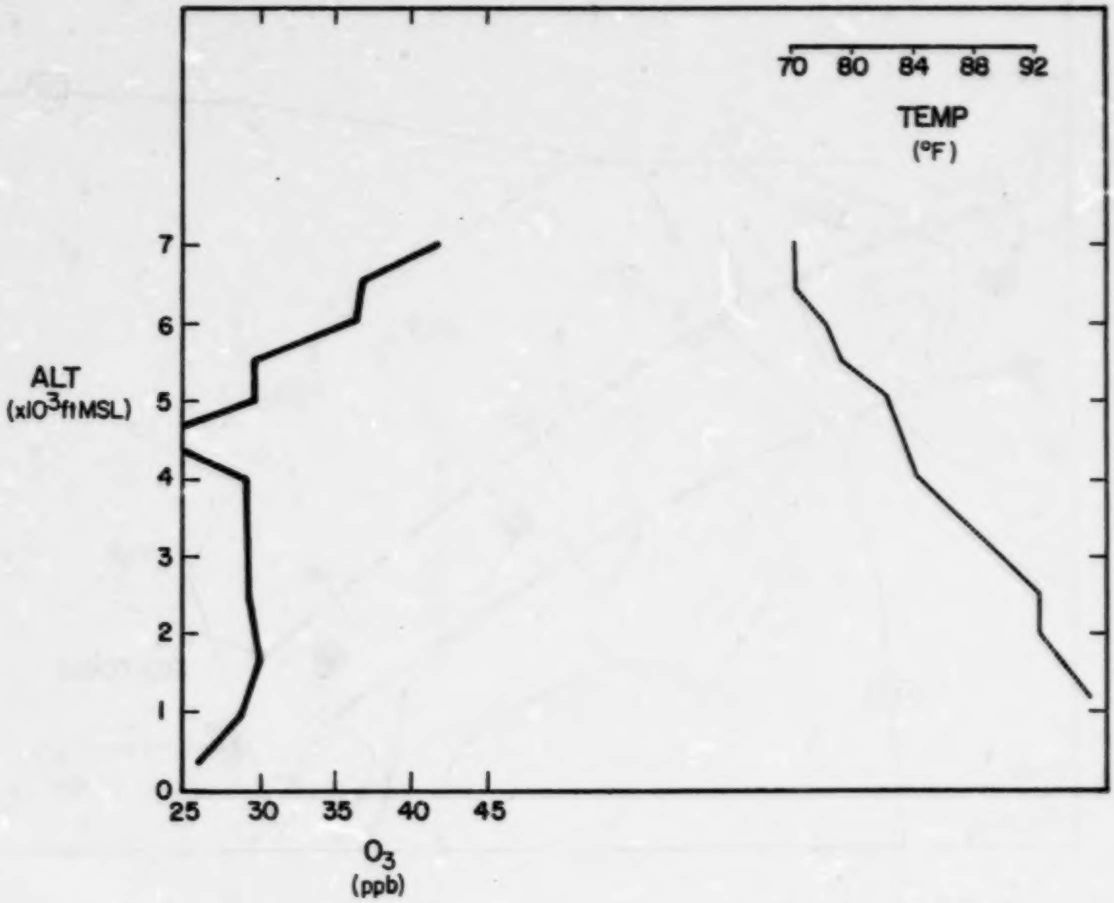


Figure B76 Vertical ozone and temperature profiles W of Houston (flt. #25: point b) at 9:05 AM on July 22, 1976.

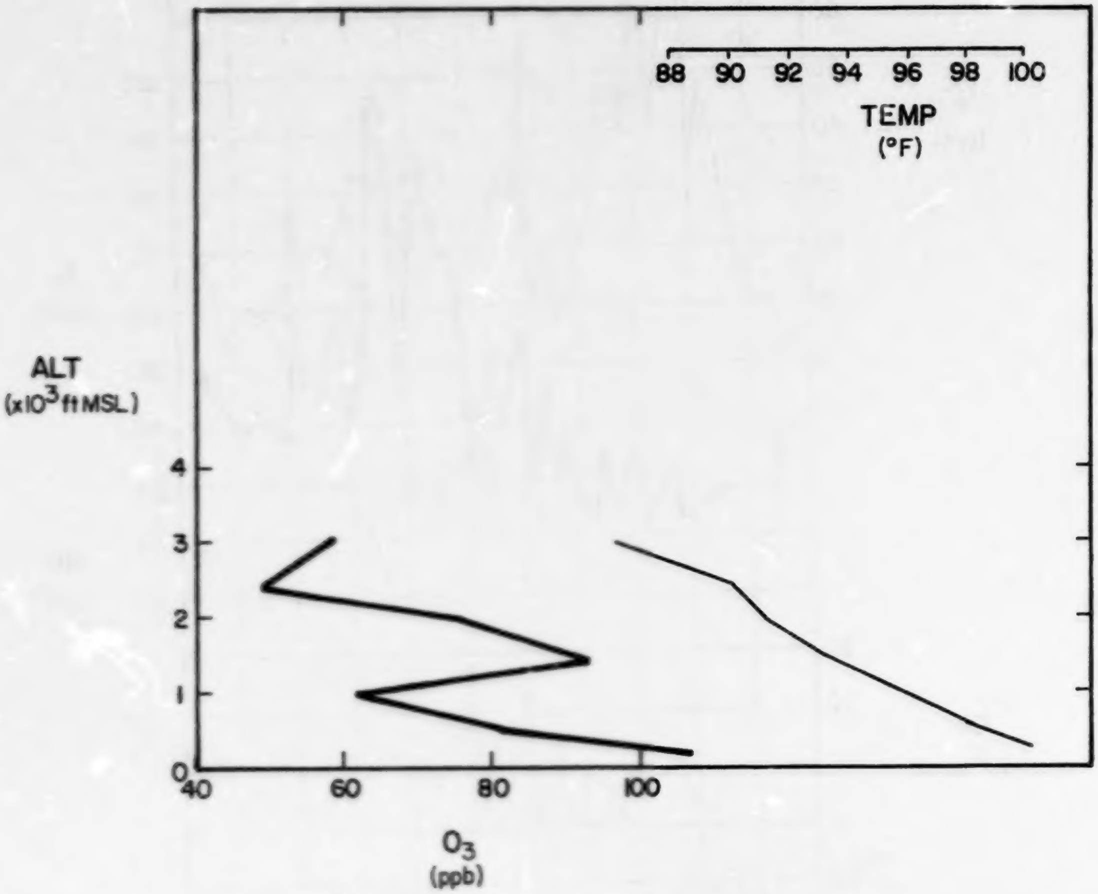


Figure B 77 Vertical ozone and temperature profiles 7.5 miles downwind of Exxon's Baytown Refinery at 10:10 AM on July 22, 1976.

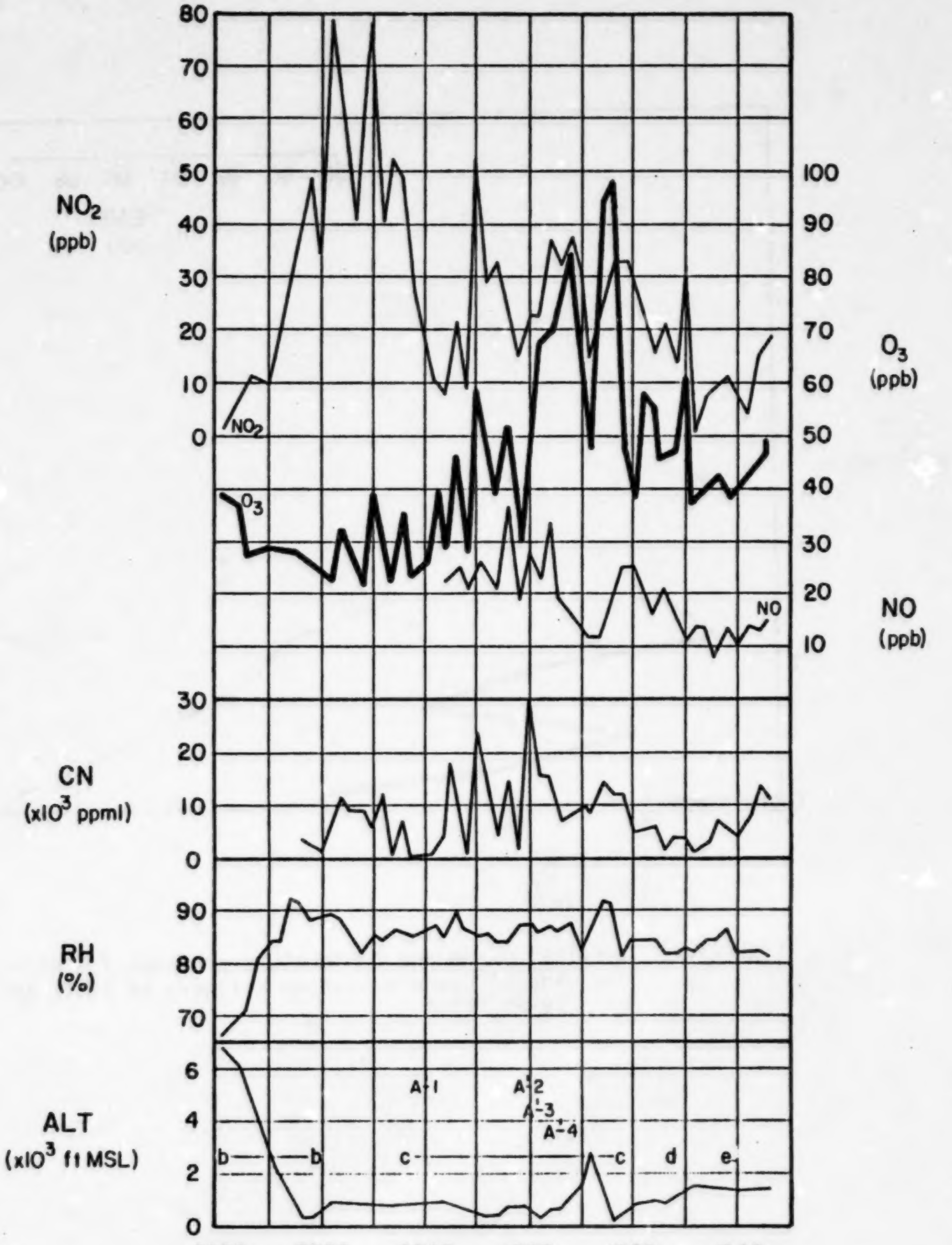


Figure B78 Plot of aircraft data recorded during Flight #25 on July 25, 1976.

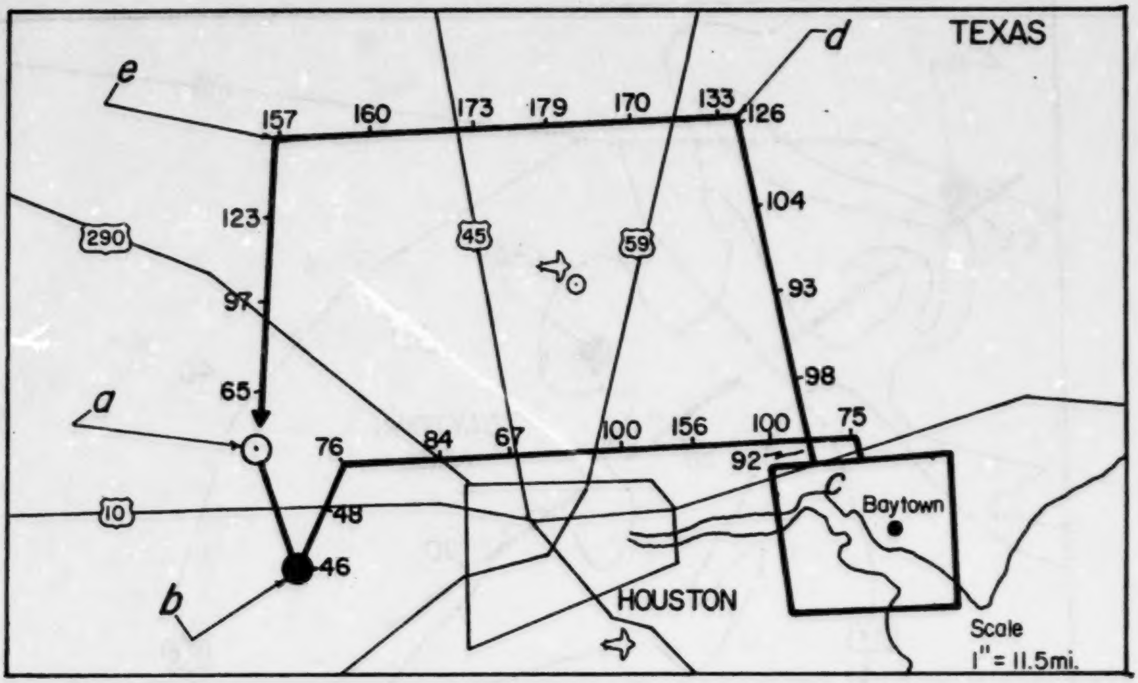

TEXAS
e
d
157
160
173
179
170
133
126
123
104
290
45
59
97
93
65
98
a
76
84
67
100
156
100
75
92
c
Baytown
10
48
46
b
HOUSTON
Scale
1" = 11.5mi.

Figure B 79 Flight #26 on July 22, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 12:50 to 3:15 PM

Leg
ab: 12:50 - 1:09 slant and spiral climb to 9000' MSL
b: 1:10 - 1:28 spiral descent to 200'
bc: 1:29 - 1:50 at ~1000'
c: 1:51 - 2:41 Refinery investigation and sample collections, ~1000'
cd: 2:42 - 2:49 at ~1000'
de: 2:50 - 3:02 at ~1000'
ea: 3:03 - 3:15 at ~1000'

WIND: IAH,110/6 HUB,150/6

WEATHER: Some scattered clouds - visibility 6 to 7 miles in haze and smoke - 90°F

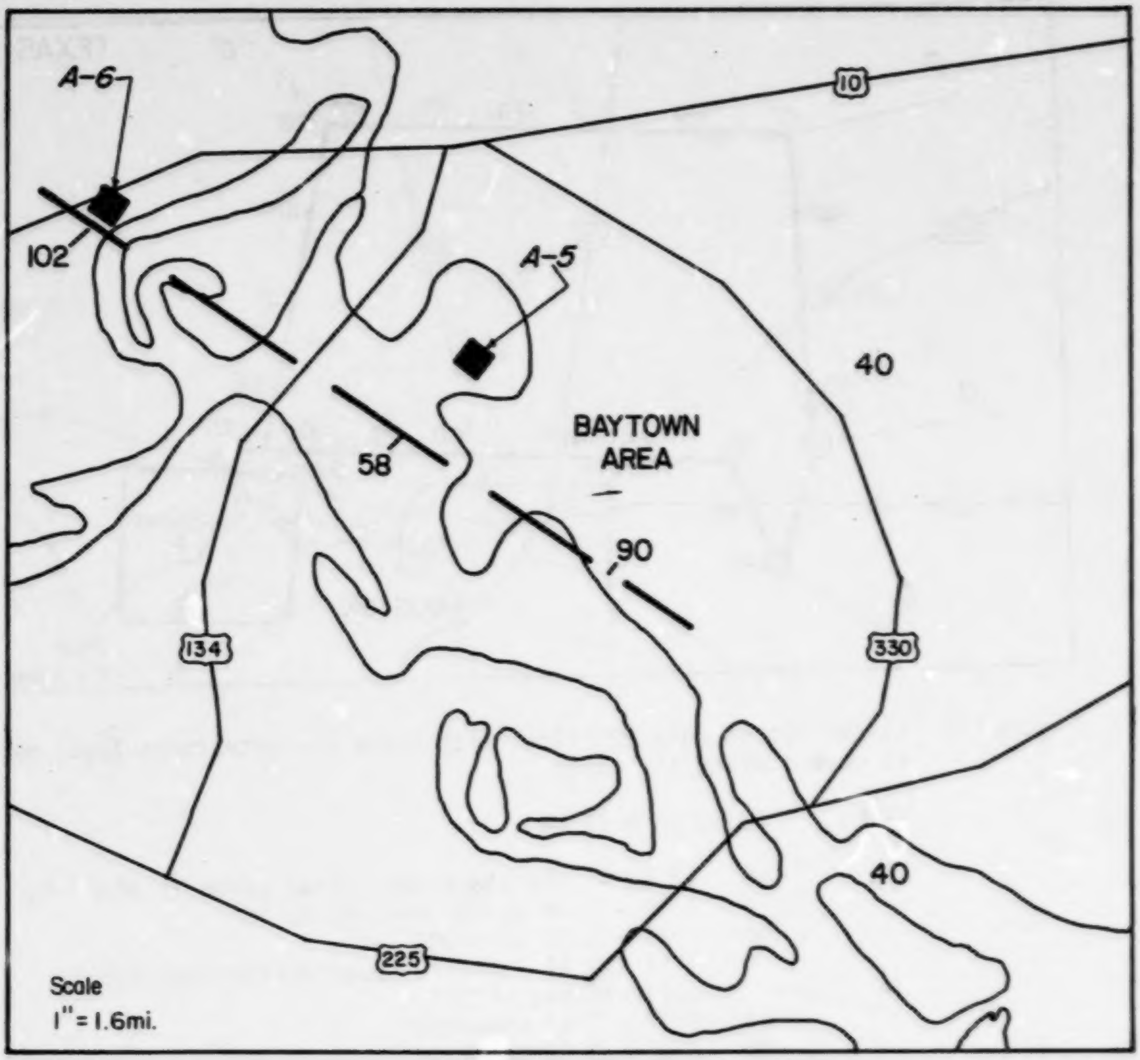

A-6
10
102
A-5
40
BAYTOWN
AREA
58
90
134
330
40
225
Scale
1" = 1.6mi.

Figure B79 Flight #26 on July 22, 1976, continued.

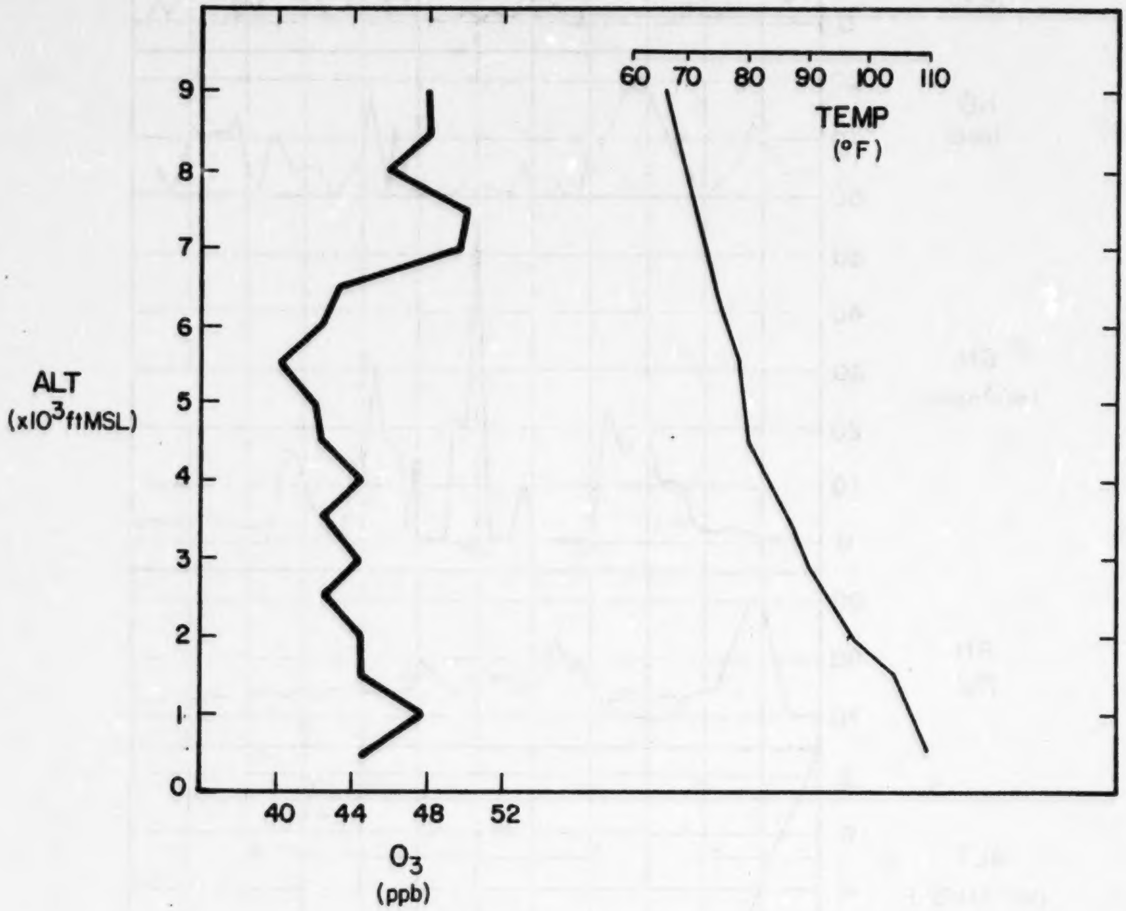


Figure B80 Vertical ozone and temperature profiles W of Houston (flt. #26: point b) at 1:15 PM on July 22, 1976.

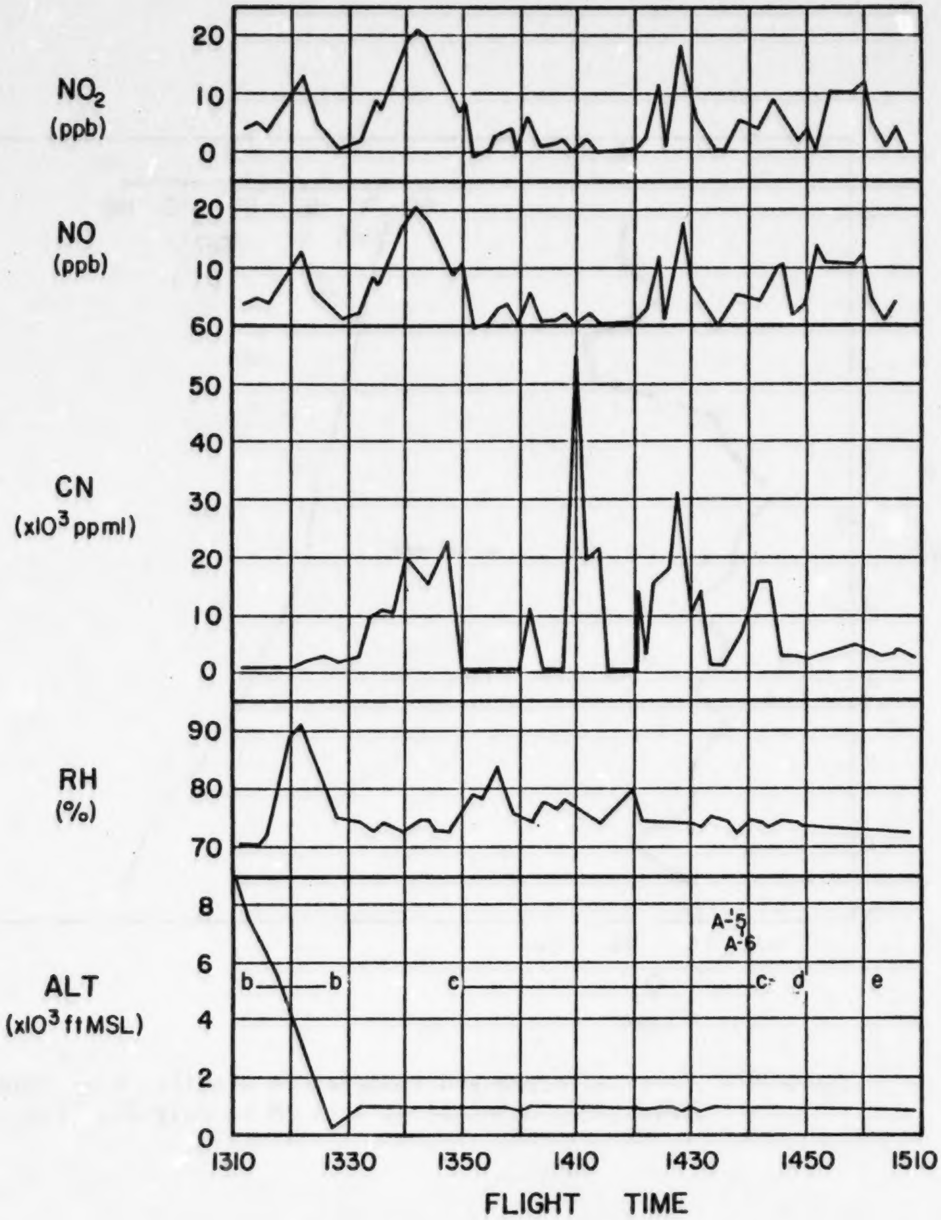


Figure B 81 Plot of aircraft data recorded during Flight #26 on July 22, 1976.

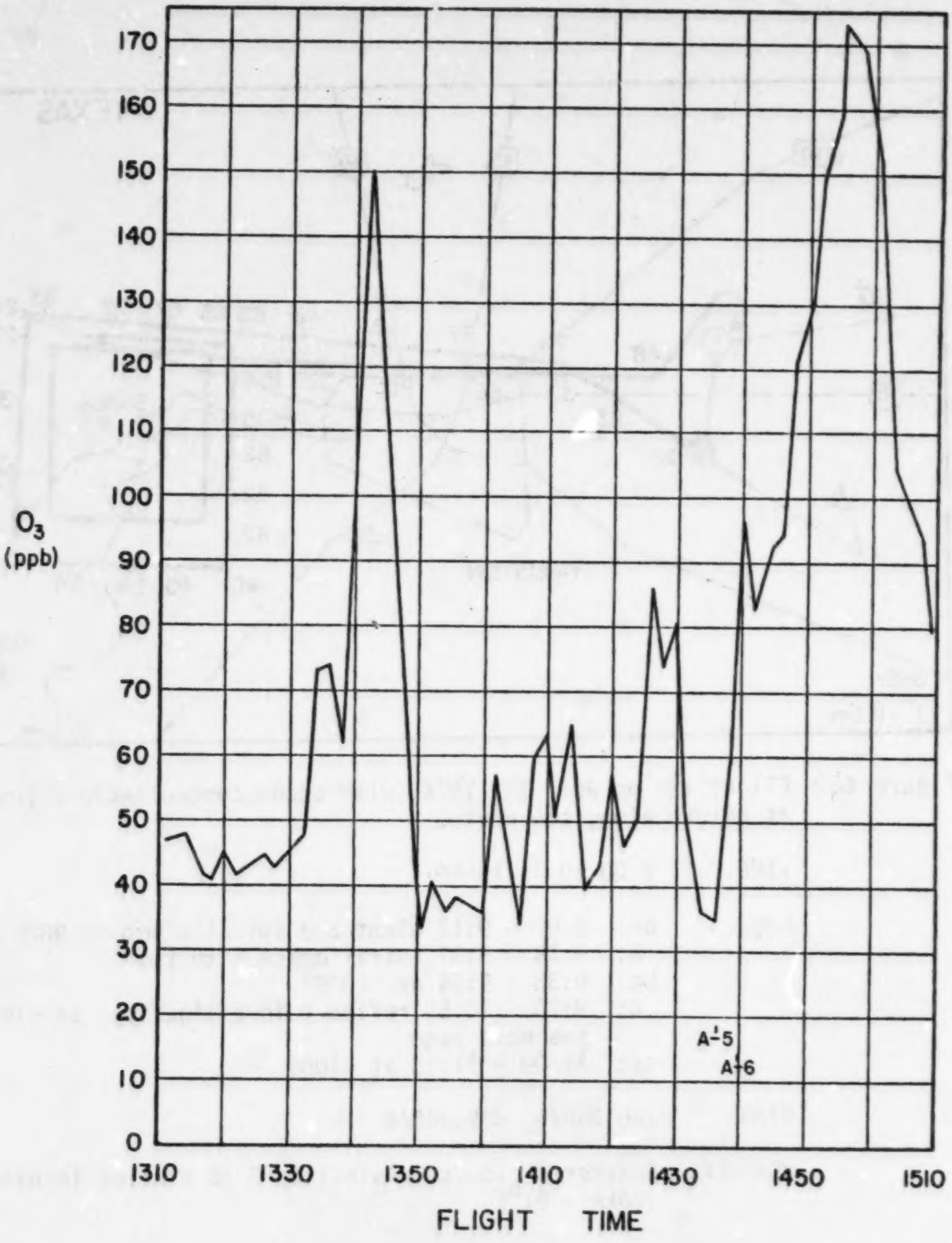


Figure B 81 Continued

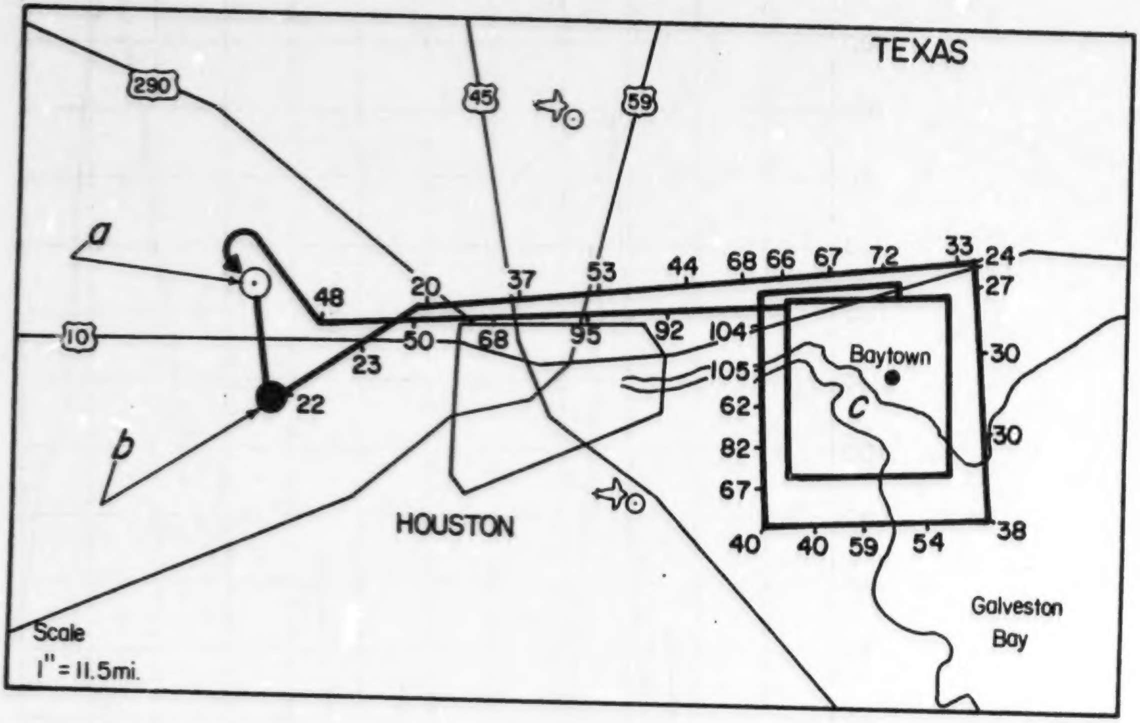

TEXAS
290
45
59
10
a
b
c
48
20
37
53
44
68
66
67
72
33
24
27
30
30
38
54
59
40
40
67
82
62
105
104
92
95
68
50
23
22
Baytown
HOUSTON
Galveston Bay
Scale
1" = 11.5mi.

Figure B82 Flight #27 on July 23, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 9:00 to 11:15 AM

Leg
ab: 9:00 - 9:17 slant and spiral climb to 9000' MSL
b: 9:18 - 9:37 spiral descent to 200'
bc: 9:38 - 9:54 at ∿1000'
c: 9:55 - 10:59 refinery investigation, at ∿1000', see next page
ca: 11:00 - 11:15 at ∿1000'

WIND: IAH,030/5 HUB,360/4

WEATHER: Scattered clouds - visibility 5 to 6 miles in haze and smoke - 81^{o}F

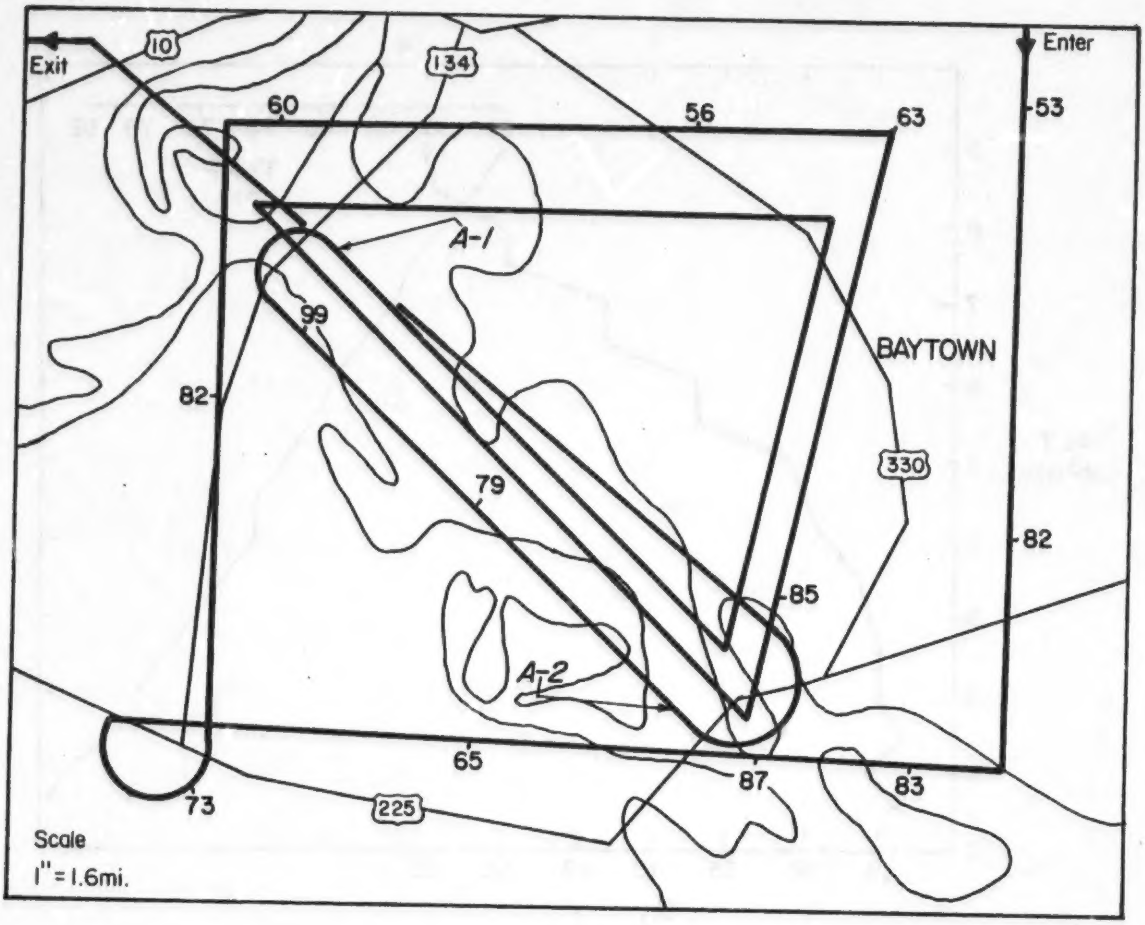

Exit
10
134
Enter
60
56
63
53
A-1
99
BAYTOWN
82
330
79
82
85
A-2
65
87
83
73
225
Scale
1" = 1.6mi.

Figure B 82 Flight #27, July 23, 1976 continued.

Area c: 9:55 - 10:59 AM

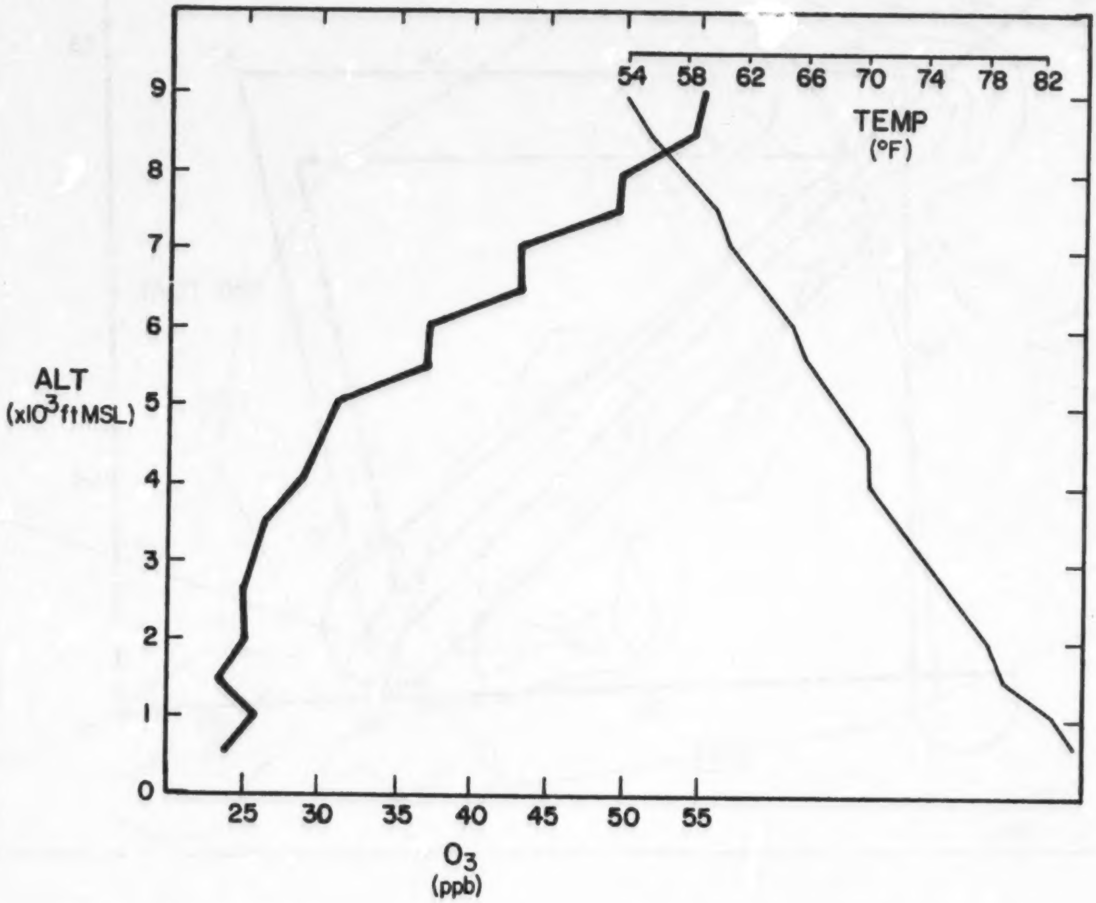


Figure B 83 Vertical ozone and temperature profiles W of Houston (flt. #27: point b) at 9:25 AM on July 23, 1976.

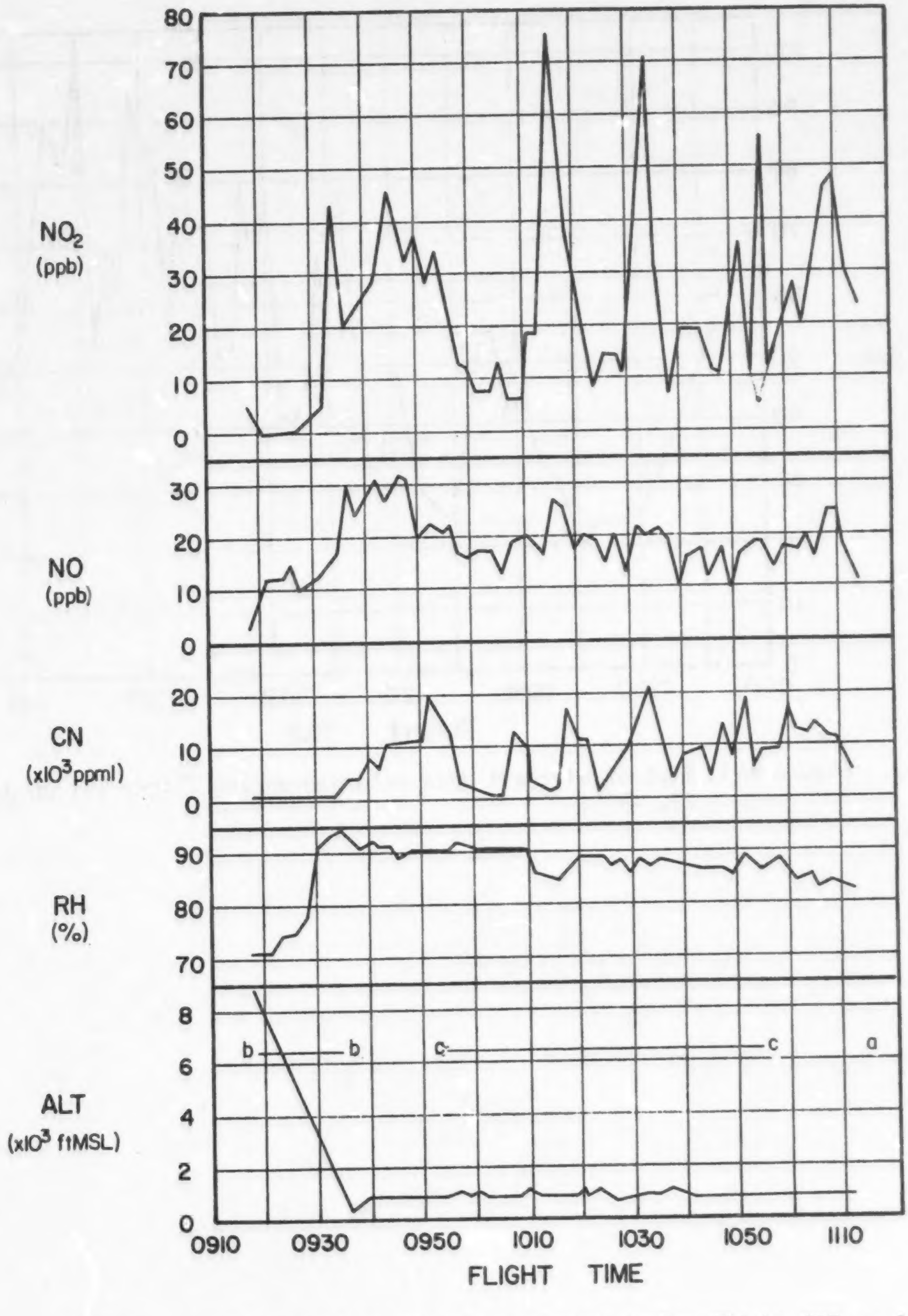


Figure B8 4 Plot of aircraft data recorded during flight #27 on July 23, 1976.

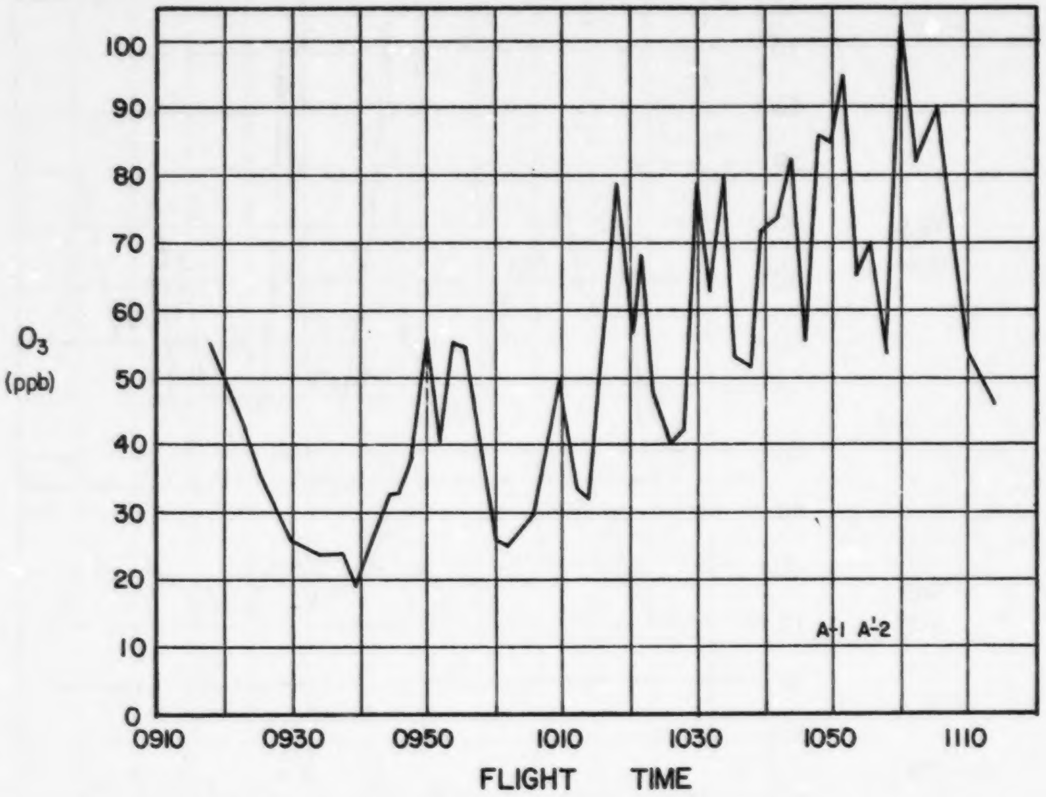
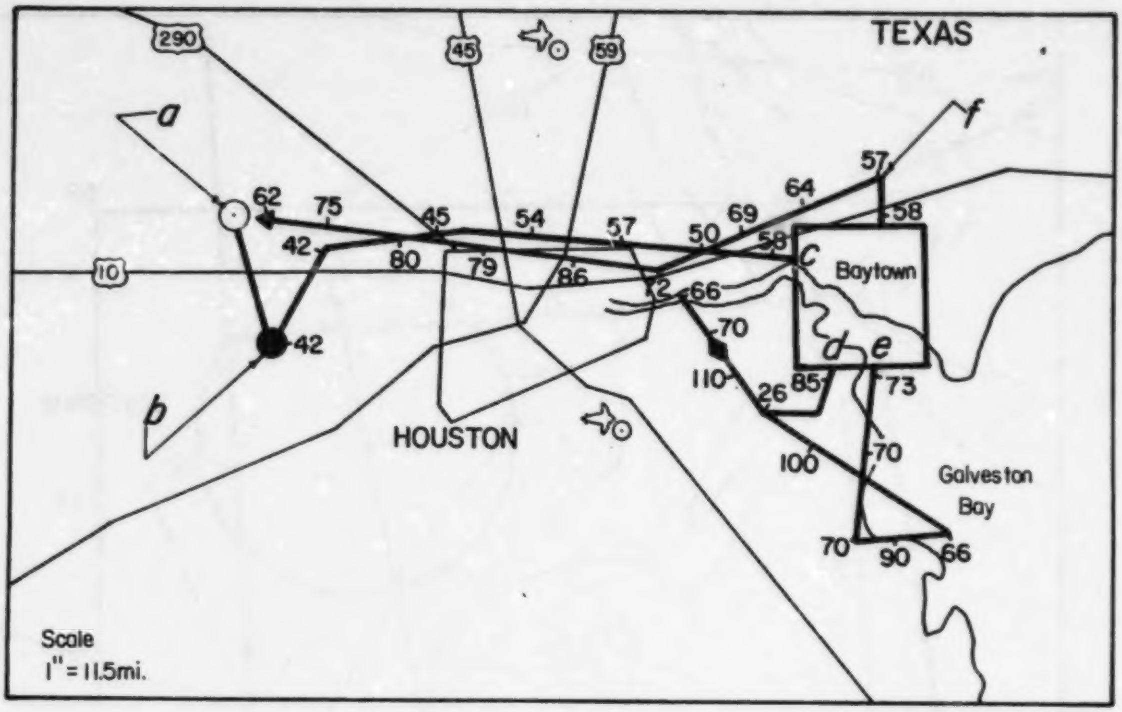


Figure B84 Plot of aircraft data recorded during flight #27 on July 23, 1976.



TEXAS
290
45
59
10
a
b
f
c
d
e
Baytown
HOUSTON
Galveston Bay
62
75
45
54
57
50
69
64
57
58
58
42
80
79
86
72
66
70
110
26
85
73
100
70
70
90
66
42
Scale
1" = 11.5mi.

Figure B 85 Flight #28 on July 24, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 10:15 - 11:55 AM

Leg
ab: 10:15 - 10:21 slant and spiral climb to 6500' MSL
b: 10:22 - 10:34 spiral descent to 1000'
bc: 10:35 - 10:49 at 1000'
cd: 10:50 - 11:10 at ∿1000'
de: 11:11 - 11:33 at ∿1000'
ef: 11:34 - 11:36 at ∿1000'
fa: 11:37 - 11:55 at ∿1000'

WIND: HUB,320/8

WEATHER: Clear - 85°F

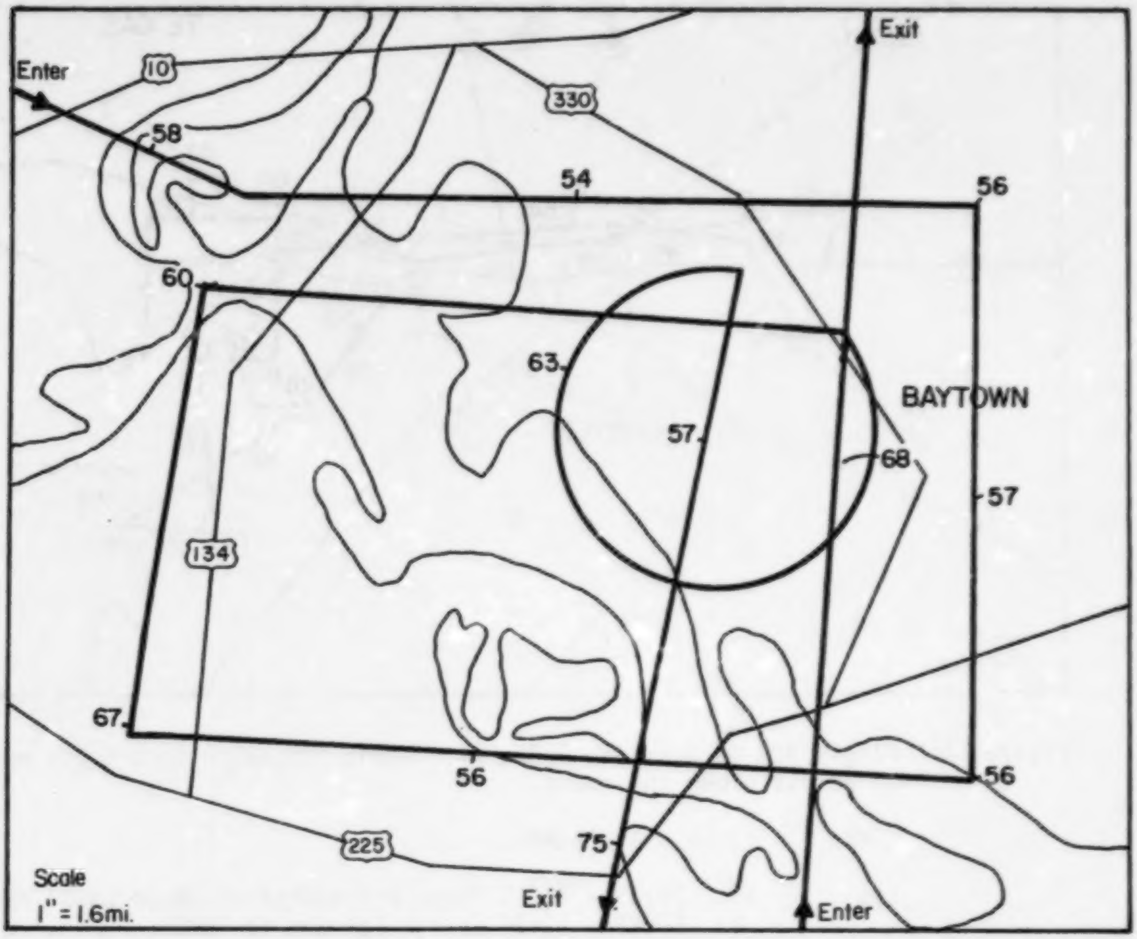

Enter
10
330
58
54
56
Exit
60
63
57
BAYTOWN
68
57
134
67
56
56
75
225
Scale
1" = 1.6mi.
Exit
Enter

Figure B 85 Flight #28 on July 24, 1976, continued.

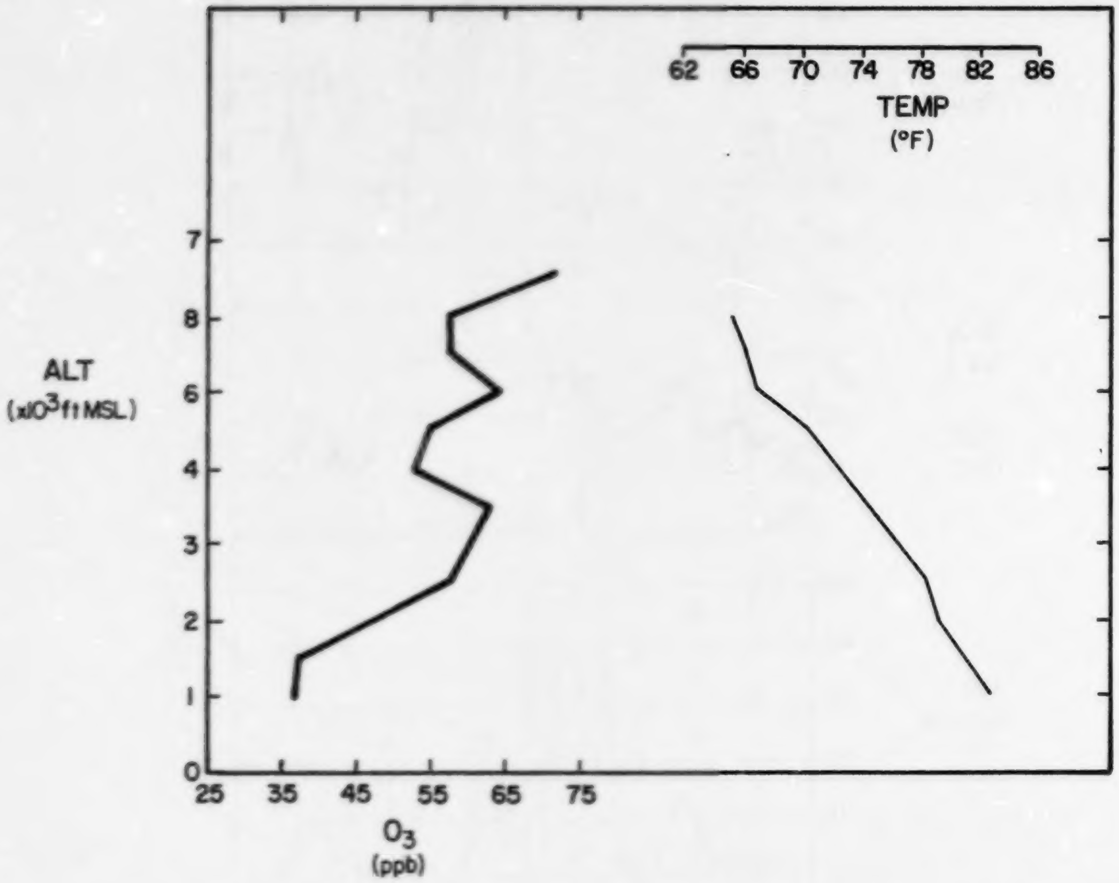


Figure B 86 Vertical ozone and temperature profiles W of Houston (flt. #28: point b) at 10:30 AM on July 24, 1976.

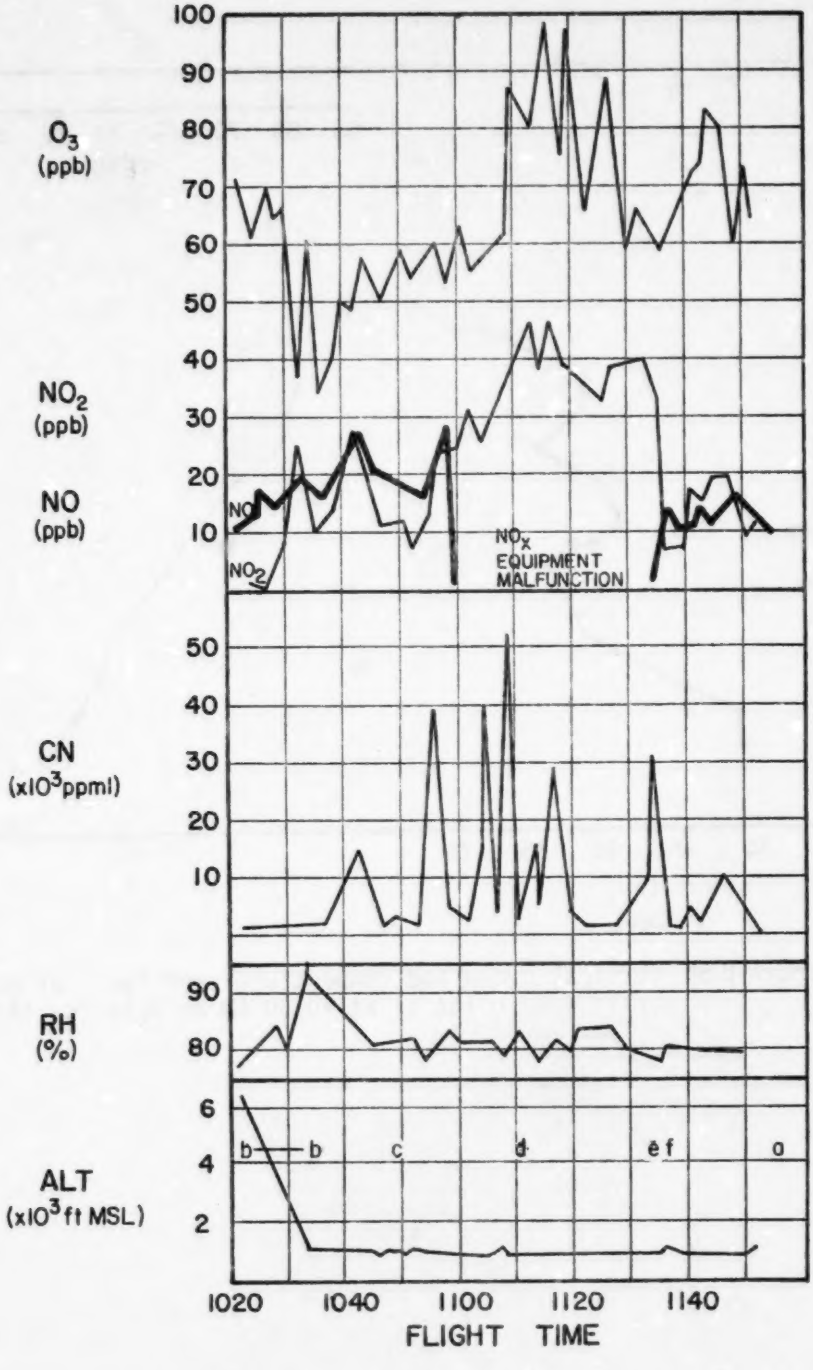


Figure 287 Plot of aircraft data recorded during flight #28
on July 24, 1976.

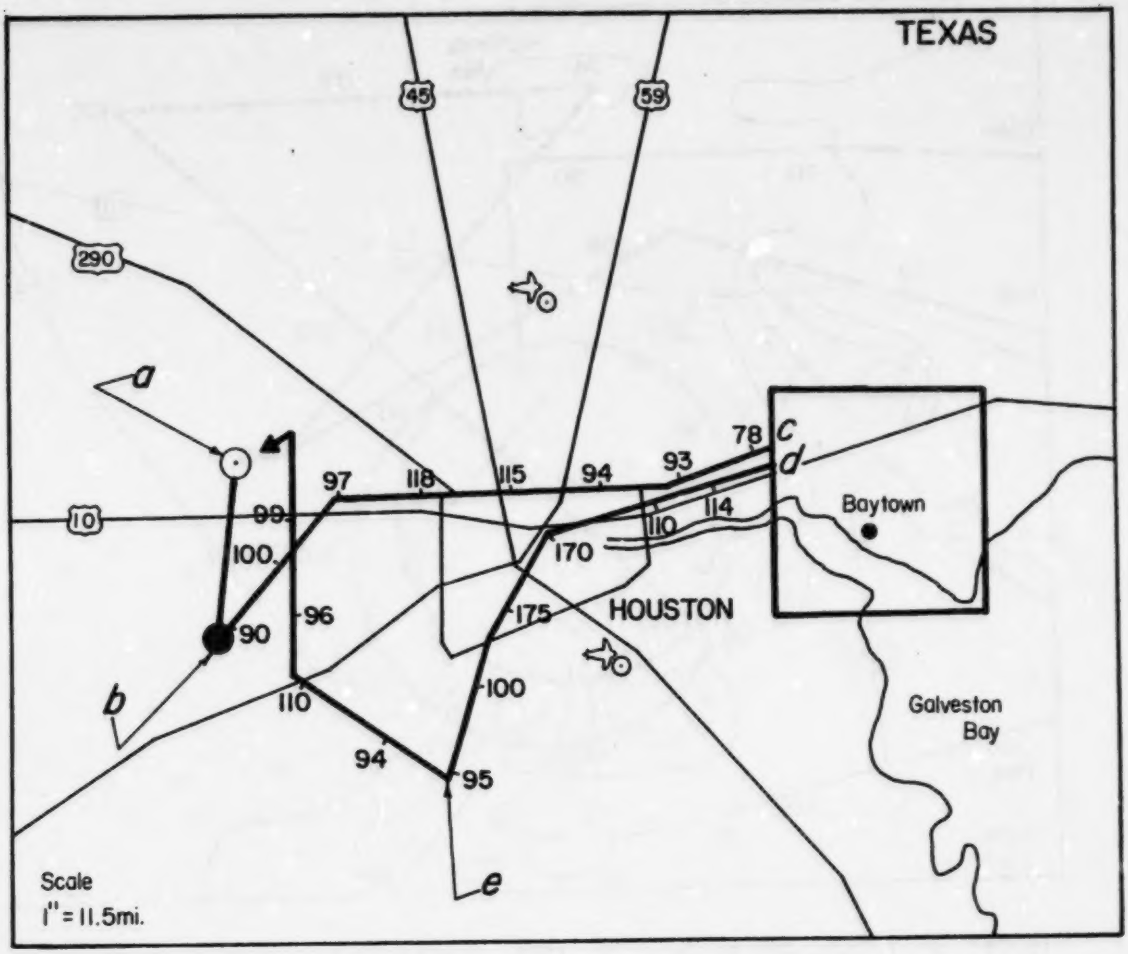

TEXAS
45
59
290
10
a
b
c
d
e
78
93
94
115
118
97
99
100
90
96
110
94
95
100
175
170
110
114
Baytown
HOUSTON
Galveston Bay
Scale
1" = 11.5mi.

Figure B 88 Flight #29 on July 24, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 2:33 - 4:25 PM

Leg	ab:	2:33 - 2:50 slant and spiral climb to 10,000' MSL
	b:	2:51 - 3:13 spiral descent to 200'
	bc:	3:14 - 3:30 at 1500'
	cd:	3:31 - 3:55 at ∿1500'
	de:	3:56 - 4:08 at 1500'
	ea:	4:09 - 4:25 at 1500'

WIND: HUB,170/5

WEATHER: Broken clouds at 3000' - reduced visibility in haze - 90°F

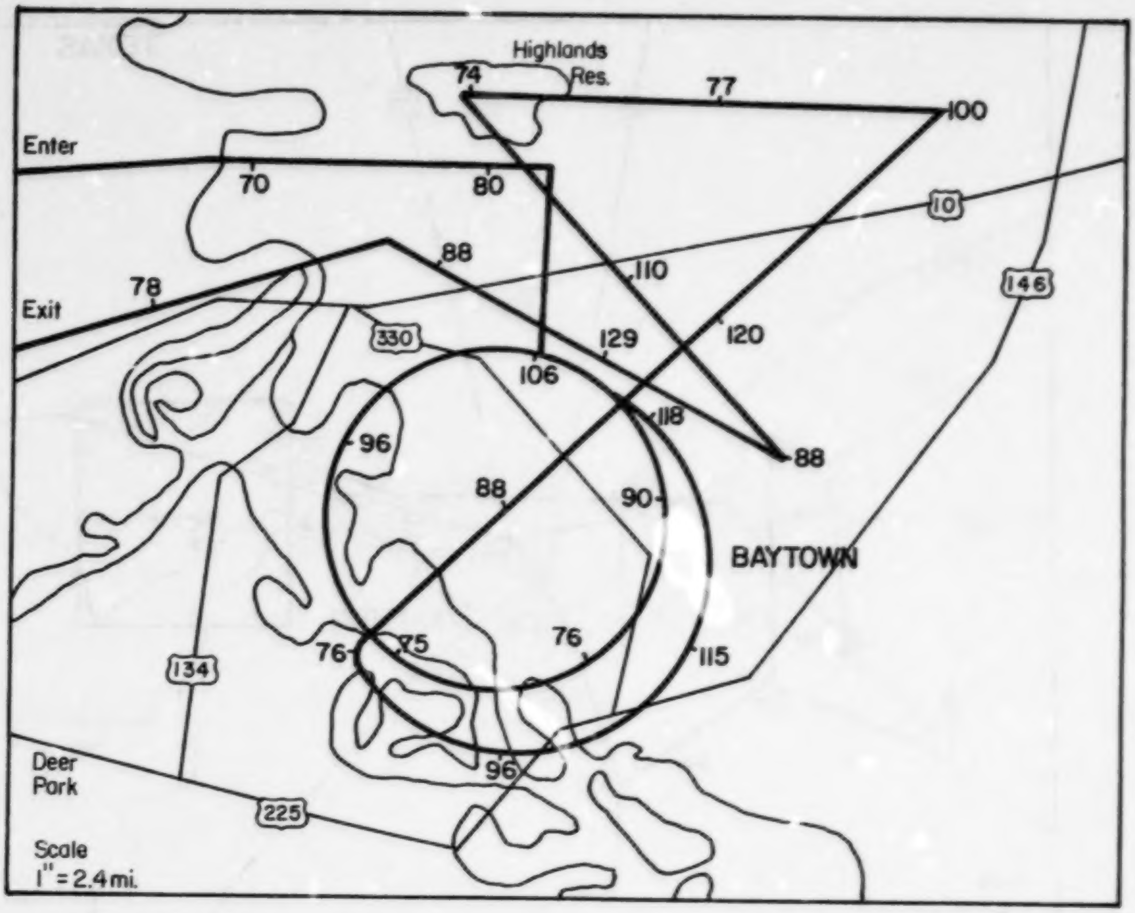

Highlands
Res.
74
77
100
Enter
70
80
10
88
110
Exit
78
120
146
330
129
106
118
96
88
88
90
BAYTOWN
76
75
76
115
134
96
Deer
Park
225
Scale
1" = 2.4 mi.

Figure B 88 Flight #29 on July 24, 1976, continued.

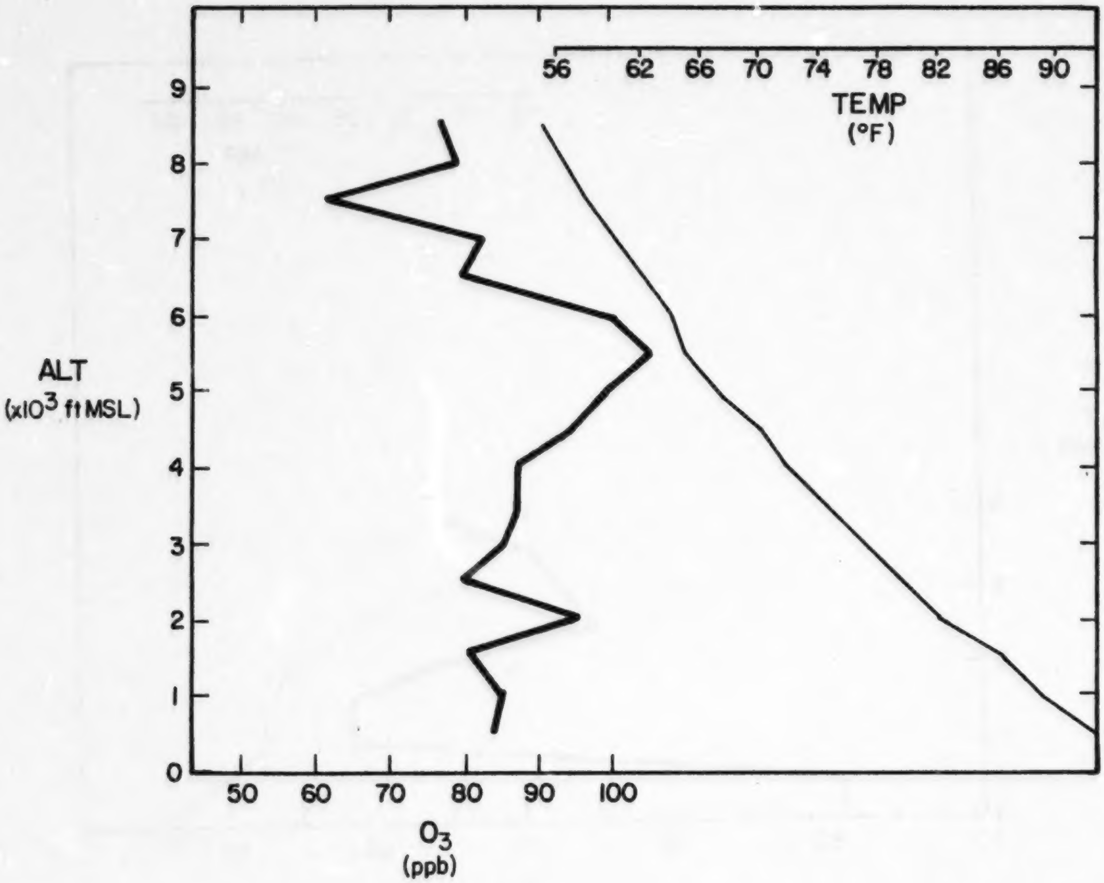


Figure B89 Vertical ozone and temperature profiles W of Houston (flt. #29: point b) at 3:00 PM on July 24, 1976.

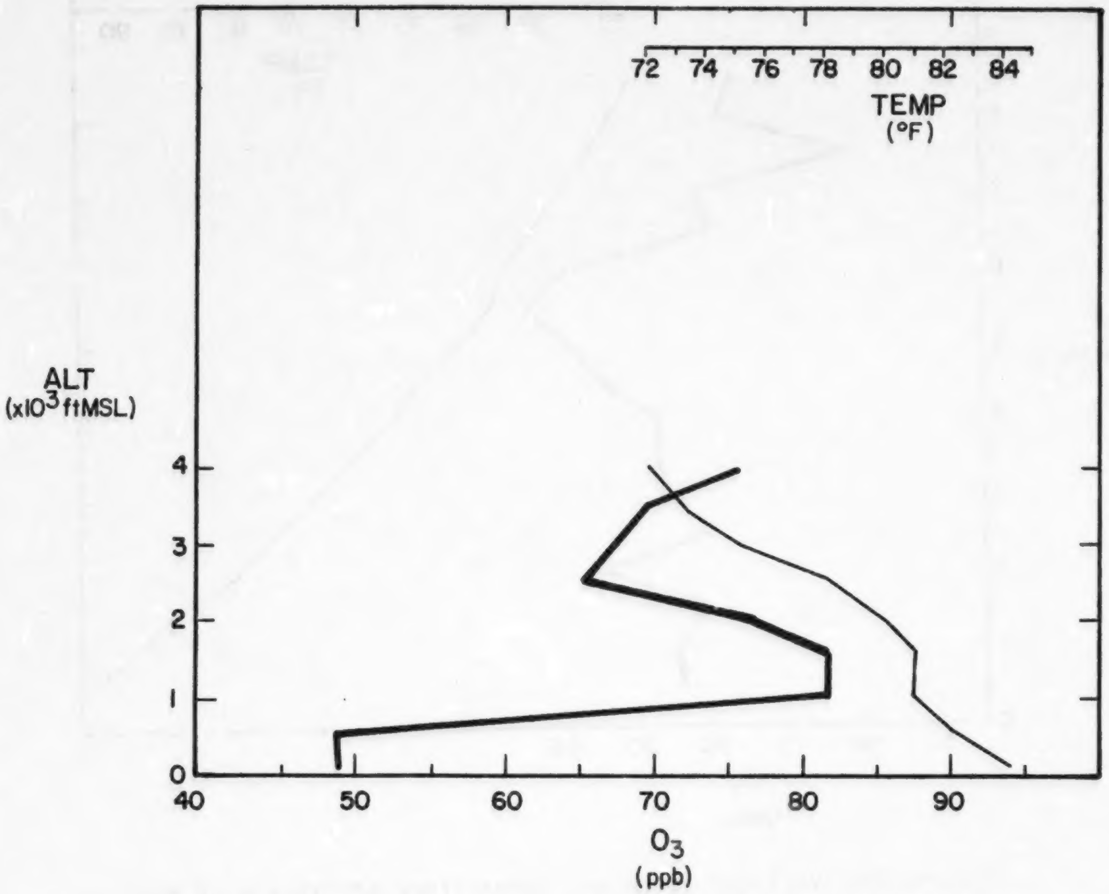


Figure B93 Vertical ozone and temperature profiles SW of Houston (flt. #30: point f) at 10:30 AM on July 25, 1976.

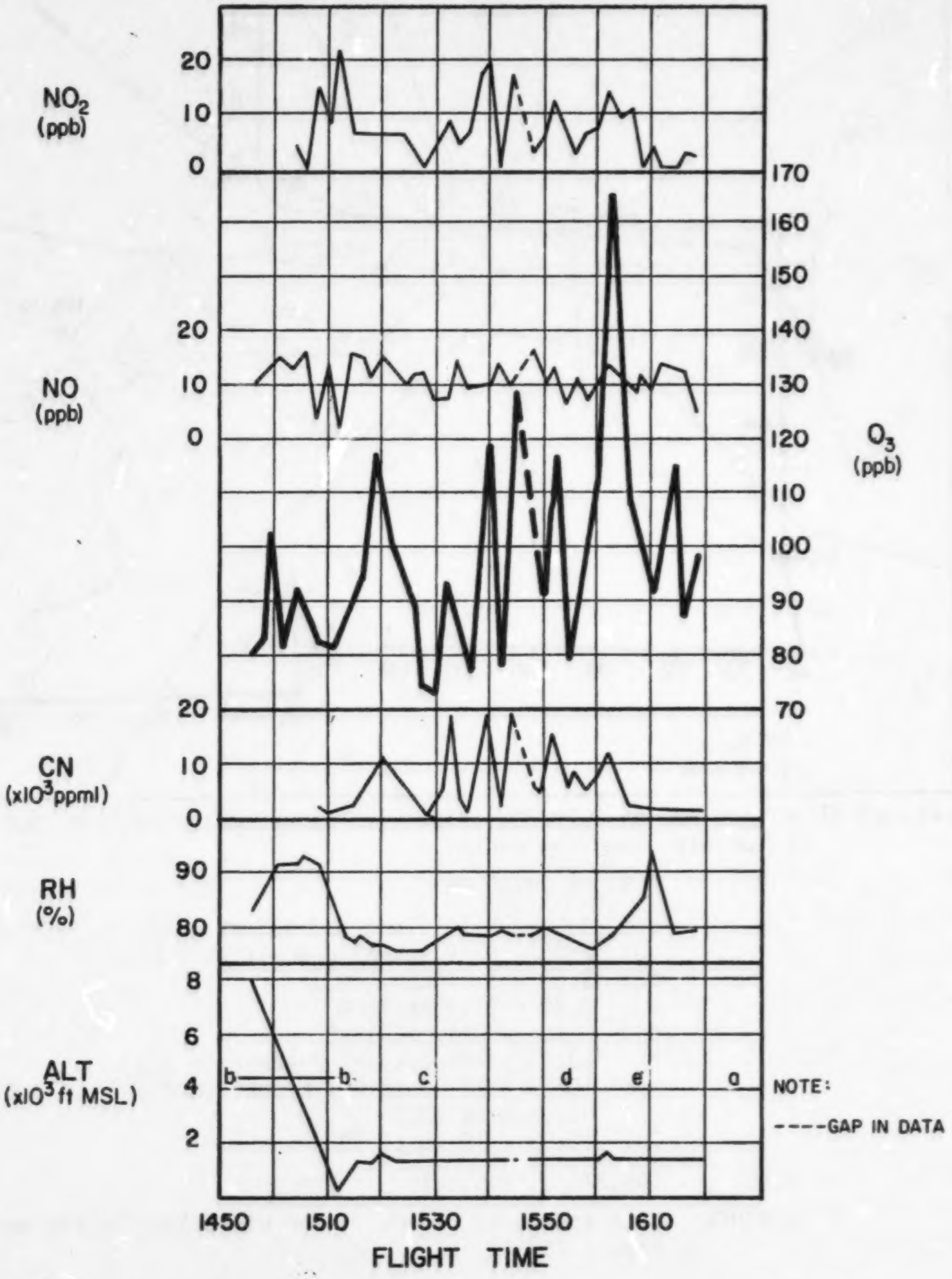


Figure.B90 Plot of aircraft data recorded during flight #29 on July 24, 1976.

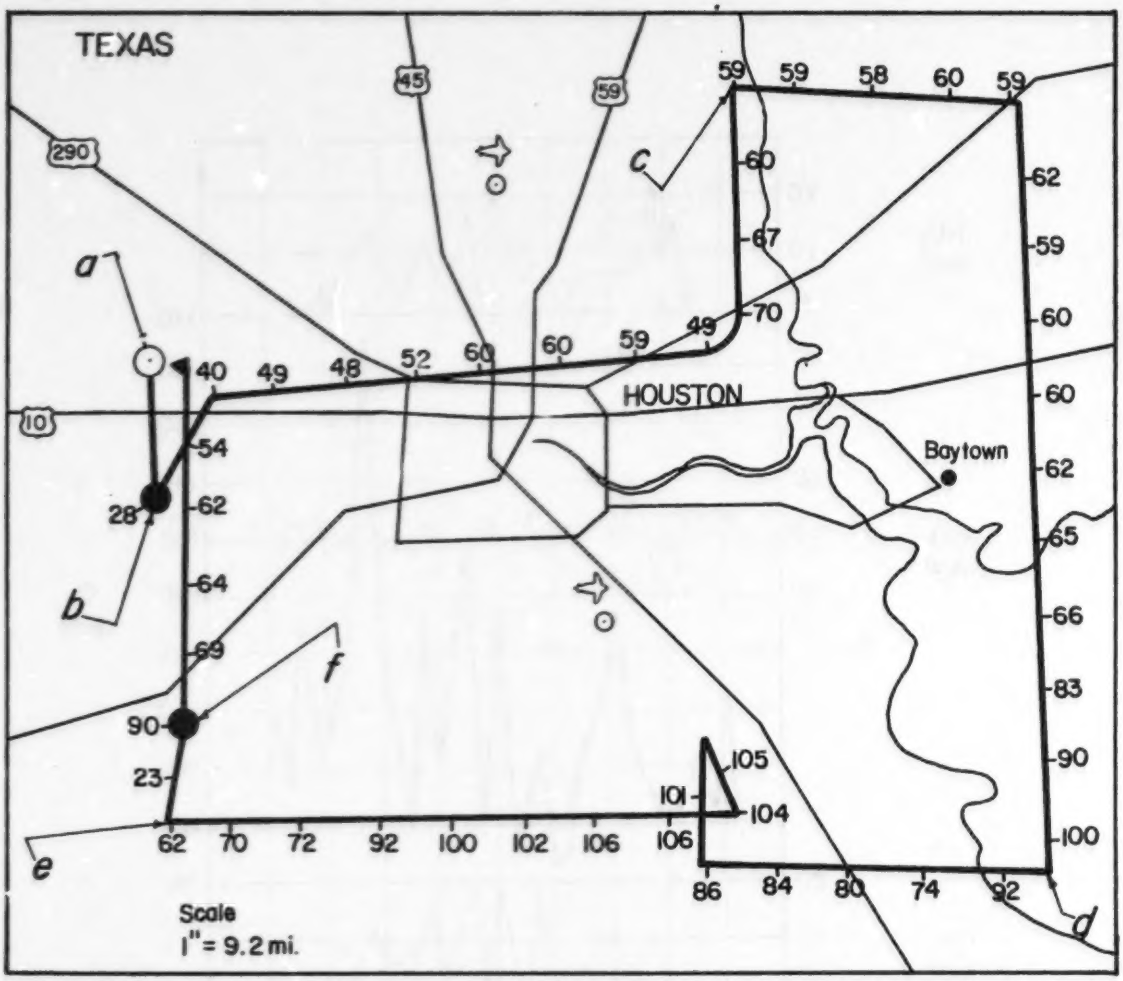

TEXAS
45
59
290
10
HOUSTON
Baytown
a
b
c
d
e
f
59 59 58 60 59
-60
-67
-70
49
59
60
60
52
48
49
40
54
28
-62
-64
-69
90
23
-62
-59
-60
-60
-62
-65
-66
-83
-90
-100
62 70 72 92 100 102 106 106
101
105
104
86 84 80 74 92
Scale
1" = 9.2 mi.

Figure B-91 Flight #30 on July 25, 1976, with ozone concentrations (ppb) marked at points along the route.

TIME: 8:35 to 10:45 AM

Leg
ab: 8:35 - 8:44 slant and spiral climb to 7000' MSL
b: 8:45 - 8:59 spiral descent to 200'
bc: 9:00 - 9:21 at 1000'
cd: 9:22 - 9:49 at 1000'
de: 9:50 - 10:17 at 1000'
ef: 10:18 - 10:22 slant descent to 200'
f: 10:23 - 10:32 spiral ascent to 4000' and spiral descent to 1300'
fa: 10:33 - 10:45 at 1300'

WIND: IAH,270/2 HUB,calm

WEATHER: High scattered clouds - poor visibility in fog and haze - 75^{o}F

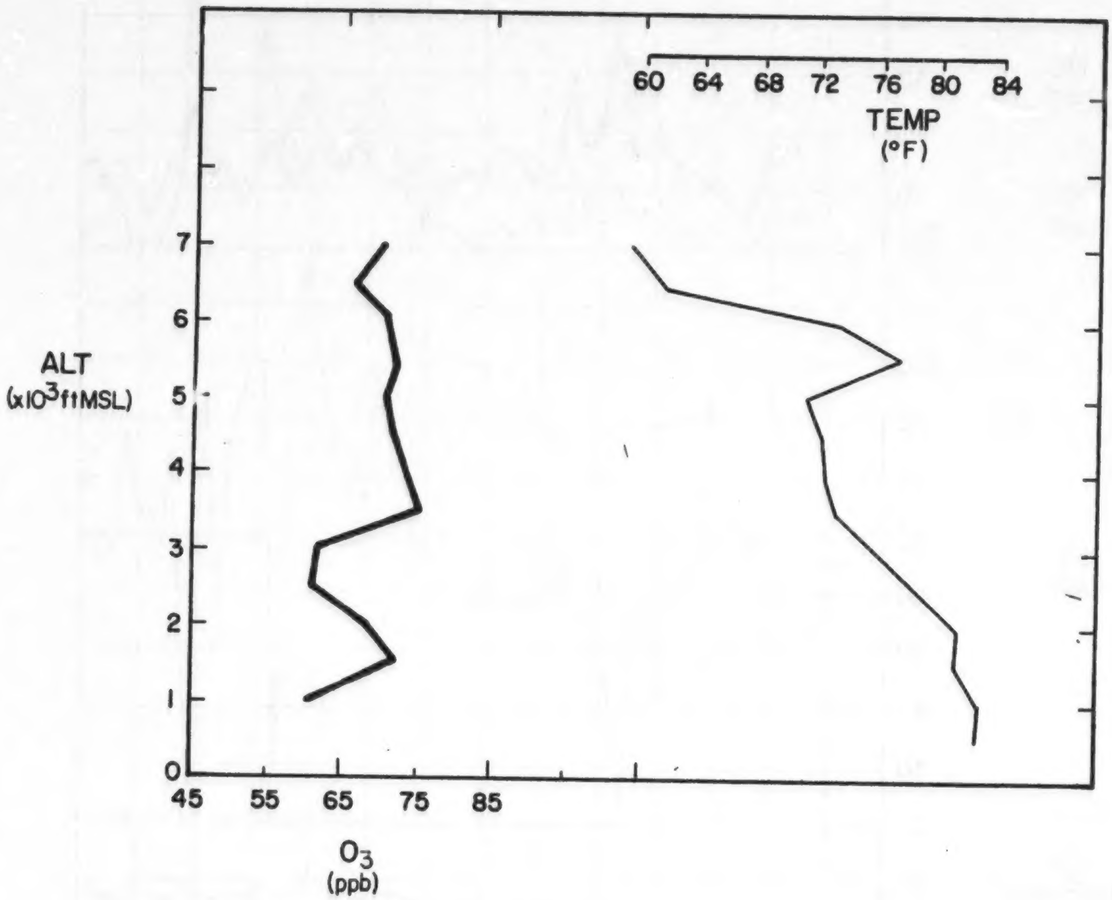


Figure B92 Vertical ozone and temperature profiles W of Houston (flt. #30: point b) at 8:50 AM on July 25, 1976.

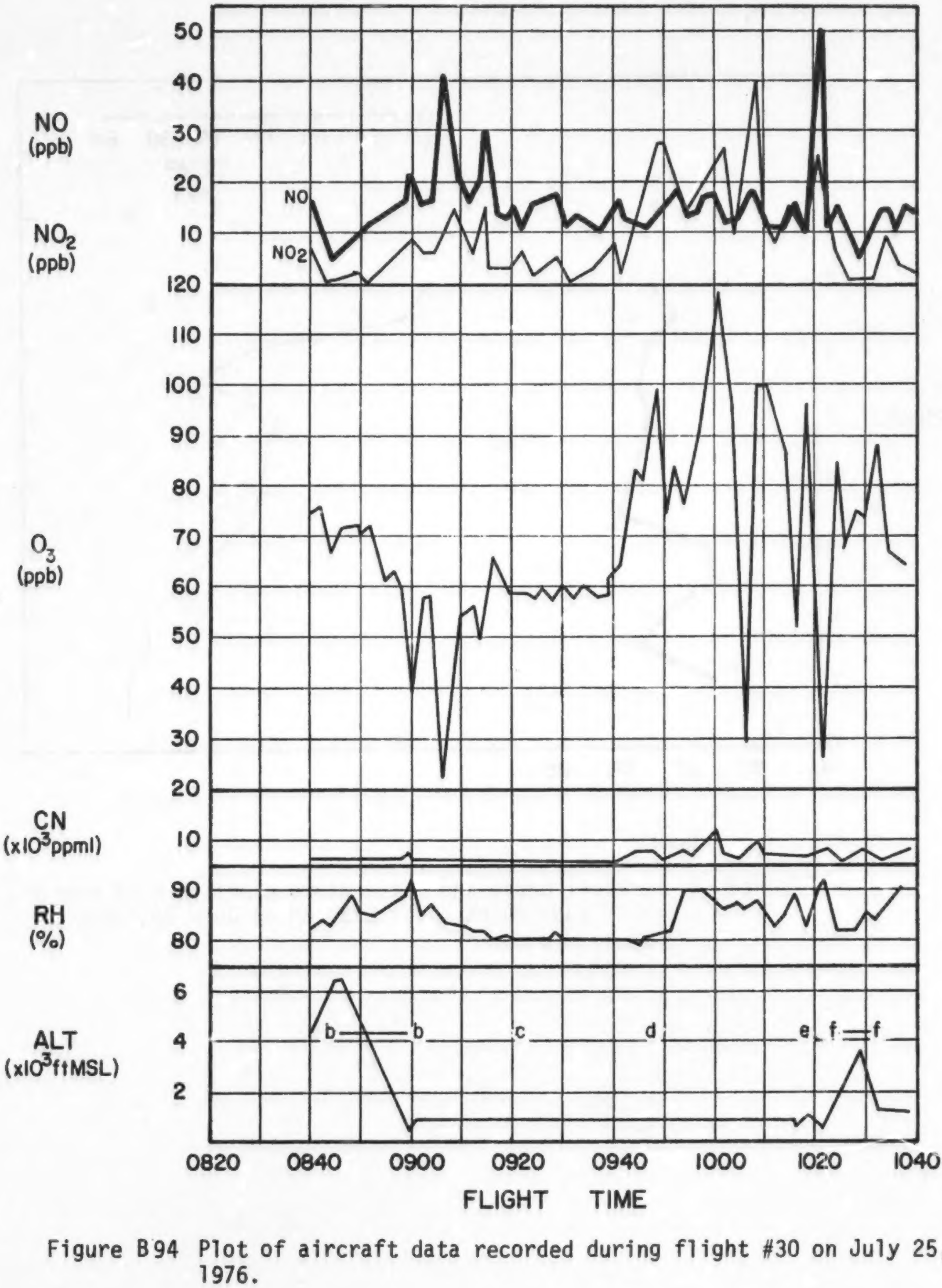


Figure B94 Plot of aircraft data recorded during flight #30 on July 25, 1976.

APPENDIX C

The summation of all individual hydrocarbon peaks for samples listed in Tables 3, 4, 5, 7, 11 and 12 are tabulated in this section.

TABLE C-1. SUMMATION OF INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED BETWEEN 6 AND 9 AM AT THE WSU TRAILER SITE.

DATE	TOTAL IDENTIFIED IN TABLE 3	TOTAL OF OTHER HYDROCARBON SPECIES NOT INCLUDED IN TABLE 3 (IDENTIFIED AND UNIDENTIFIED)	TOTAL NMHC BY SUMMING INDIVIDUAL SPECIES
7/5	206	93	299
7/7	265	143	408
7/8	593	267	860
7/9	407	179	586
7/10	275	126	401
7/12	719	378	1097
7/13	533	268	801
7/14	130	123	253
7/15	2527	1662	4189
7/16	461	350	811
7/17	549	293	842
7/19	1153	464	1617
7/20	488	436	924
7/21	595	373	968
7/22	697	647	1344
7/23	709	392	1101
7/24	1257	258	1515

TABLE C-2. SUMMATION OF INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED BETWEEN 7 AND 9 AM AT THE SOUTH SITE.

DATE	TOTAL IDENTIFIED IN TABLE 4	TOTAL OF OTHER HYDROCARBON SPECIES NOT INCLUDED IN TABLE 4 (IDENTIFIED AND UNIDENTIFIED)	TOTAL NMHC BY SUMMING INDIVIDUAL SPECIES
7/9	889	165	1054
7/10	158	79	237
7/13	714	332	1046
7/14	601	360	961
7/15	244	127	371
7/16	193	129	322
7/17	275	167	442
7/19	677	2051	2728
7/20	179	158	337
7/22	461	301	762

TABLE C-3. SUMMATION OF INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED BETWEEN 6 AND 9 AM AT THE NORTH SITE.

DATE	TOTAL IDENTIFIED IN TABLE 5	TOTAL OF OTHER HYDROCARBON SPECIES NOT INCLUDED IN TABLE 5 (IDENTIFIED AND UNIDENTIFIED)	TOTAL NMHC BY SUMMING INDIVIDUAL SPECIES
7/9	280	280	560
7/10	308	245	553
7/12	951	1590	2541
7/14	120	138	258
7/16	440	363	803
7/17	2256	4450	6706
7/19	2893	8005	10898
7/20	376	380	756
7/21	2375	4696	7071

TABLE C-4. SUMMATION OF INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED DURING THE AFTERNOON HOURS AT THE WSU TRAILER SITE.

DATE	TOTAL IDENTIFIED IN TABLE 7	TOTAL OF OTHER HYDROCARBON SPECIES NOT INCLUDED IN TABLE 7 (IDENTIFIED AND UNIDENTIFIED)	TOTAL NMHC BY SUMMING INDIVIDUAL SPECIES
7/6	90	91	181
7/9	281	162	443
7/10	221	133	354
7/12	324	167	491
7/13	104	78	182
7/14	290	169	459
7/15	256	178	434
7/17	75	67	142
7/21	504	252	756

TABLE C-5. SUMMATION OF INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES CONSIDERED TO BE REPRESENTATIVE OF BACKGROUND AIR.

DATE	TOTAL IDENTIFIED IN TABLE 11	TOTAL OF OTHER HYDROCARBON SPECIES NOT INCLUDED IN TABLE 11 (IDENTIFIED AND UNIDENTIFIED)	TOTAL NMHC BY SUMMING INDIVIDUAL SPECIES
7/4	37.0	36.0	73.0
7/7	31.5	33.5	65.0
7/12	36.0	30.0	66.0
7/14	40.0	37.5	77.5
7/20	61.0	81.0	142.0

TABLE C-6. SUMMATION OF INDIVIDUAL HYDROCARBON CONCENTRATIONS ($\mu g/m^3$) IN SAMPLES COLLECTED IN AIR MASSES CONTAINING OZONE LEVELS GREATER THAN 80 PPB.

DATE	TOTAL IDENTIFIED IN TABLE 12	TOTAL OF OTHER HYDROCARBON SPECIES NOT INCLUDED IN TABLE 12 (IDENTIFIED AND UNIDENTIFIED)	TOTAL NMHC BY SUMMING INDIVIDUAL SPECIES
7/7	434	146	580
7/8	193	69	262
7/10 (A-1)	190	40	230
7/10 (A-2)	223	82	305
7/12 (A-3)	173	39	212
7/12 (A-4)	179	121	300
7/14 (A-2)	175	64	239
7/14 (A-3)	270	108	378
7/18	120	46	166
7/20 (A-2)	185	79	264
7/20 (A-3)	121	47	168
7/22	160	54	214